AD NUMBER
AD876366
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; OCT 1970. Other requests shall be referred to Air Force Arnold Engineering Development Center, Arnold AFB, TN. This document contains export-controlled technical data.**
AUTHORITY
aedc ltr, 6 feb 1973

[redacted] ~~DEC 8 1970~~

AEDC-TR-70-220

THE EFFECT OF PLENUM VOLUME ON THE TEST SECTION FLOW CHARACTERISTICS OF A PERFORATED WALL TRANSONIC WIND TUNNEL

C. F. Anderson, A. Anderson, and O. P. Credle

ARO, Inc.

October 1970

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Arnold Engineering Development Center (XON), Arnold Air Force Station, Tennessee 37389.

PROPULSION WIND TUNNEL FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

THE EFFECT OF PLENUM VOLUME ON THE TEST SECTION FLOW CHARACTERISTICS OF A PERFORATED WALL TRANSONIC WIND TUNNEL

C. F. Anderson, A. Anderson, and O. P. Credle
ARO, Inc.

FOREWORD

The work reported herein was sponsored by Headquarters, Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Program Element 64719F.

The test results presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of AEDC, AFSC, Arnold Air Force Station, Tennessee, under Contract F40600-71-C-0002. The research originated in the von Kármán Gas Dynamic Facility and was conducted under ARO Projects No. PA0076 and VA3013 from July 1, 1969, to April 8, 1970, and the manuscript was submitted for publication on July 17, 1970.

Information in this report is embargoed under the Department of State International Traffic in Arms Regulations. This report may be released to foreign governments by departments or agencies of the U. S. Government subject to approval of the Arnold Engineering Development Center (XON), or higher authority within the Department of the Air Force. Private individuals or firms require a Department of State export license.

This technical report has been reviewed and is approved.

George F. Garey
Lt Colonel, USAF
Research and Development Division
Directorate of Technology

Joseph R. Henry
Colonel, USAF
Director of Technology

ABSTRACT

Tests were conducted in the Aerodynamic Wind Tunnel (1T) of the Propulsion Wind Tunnel Facility to determine the effects of test section plenum chamber volume on the centerline Mach number distributions, wave-cancellation properties of perforated walls, model force data, and tunnel acoustics at Mach numbers from 0.6 to 1.3. Results were obtained with plenum chambers of four different sizes at plenum-to-test section volume ratios between 8.3 and 0.8. Reducing plenum volume produced no measurable effect at Mach numbers below 0.95. At Mach numbers above 0.95, decreasing the plenum volume increased the internal plenum losses, increased the plenum suction requirements, and increased the centerline Mach number deviations; however, the Mach number deviations were small at Mach numbers below 1.15. Reducing the plenum volume also produced a small increase in the effective wall porosity but had no measurable effect on measured model forces except to increase the forebody drag coefficient at Mach numbers above 1.05. Changes in the plenum volume had no significant effect on tunnel acoustics.

CONTENTS

APPENDIX
ILLUSTRATIONS

NOMENCLATURE

A_b	Model base area, 0.02086 ft^2
C_A	Axial force coefficient, $F_A/q_\infty S$
$C_{A,B}$	Base axial force coefficient, $\left(\frac{p_\infty - p_b}{q_\infty}\right)\left(\frac{A_b}{S}\right)$
$C_{A,F}$	Forebody axial force coefficient, $C_A - C_{A,b}$
C_D	Drag coefficient, $C_{A,F} \cos\alpha + C_N \sin\alpha$
$C_{D,b}$	Base drag coefficient, $C_{A,b} \cos\alpha$

C_L	Lift coefficient, $C_N \cos \alpha - C_{A,F} \sin \alpha$
C_m	Pitching moment coefficient, $M_m/q_\infty S\bar{c}$
C_N	Normal force coefficient, $F_N/q_\infty S$
$\bar{c}$	Mean aerodynamic chord, 0.3762 ft
d	Body diameter, in.
F_A	Axial force, lb
F_N	Normal force, lb
M_m	Pitching moment about the quarter chord point of the mean aerodynamic chord, ft-lb
M_∞	Free-stream Mach number
p	Static pressure, psfa
p_b	Model base pressure, psfa
p_c	Plenum static pressure, psfa
p_t	Free-stream stagnation pressure, psfa
p_∞	Free-stream static pressure, psfa
Δp	Internal plenum wall differential pressure, $p - p_c$, psf
$\tilde{p}$	Root-mean-square fluctuating pressure, psf
q_∞	Free-stream dynamic pressure, psf
S	Model wing area, 0.1841 ft^2
x	Model station, in.
α	Model angle of attack, deg
σ	Standard deviation
τ	Wall porosity, percent

SECTION I
INTRODUCTION

Consideration of the national demand for transonic testing led to a study of methods of obtaining a transonic capability in the von Kármán Gas Dynamics Facility (VKF) 40-in. Supersonic Wind Tunnel (A) without significant modifications to the facility. The recommended method would utilize a removable plenum insert to provide a 30- by 30-in. transonic test section just upstream of the Tunnel A model injection system (Fig. 1, Appendix). The proposed insert (Fig. 2) would provide current transonic design features including variable porosity walls; however, the plenum depth and plenum volume would be considerably less than that normally used in current transonic wind tunnels.

The effect of plenum volume on transonic wind tunnel performance is relatively unknown. A survey of the literature produced only two reports concerning the effects of plenum volume on transonic wind tunnel performance (Refs. 1 and 2) and both of these reports were on slotted tunnels. Since the effects of plenum volume on a perforated wall transonic wind tunnel were unknown, an exploratory test program in the Aerodynamic Wind Tunnel (1T) of the Propulsion Wind Tunnel Facility (PWT) was conducted to determine the effects of plenum volume on test section flow characteristics of a perforated wall transonic wind tunnel. Free-stream Mach number distributions, wave-cancellation properties of perforated walls, model force data, and tunnel acoustics data were obtained. Three auxiliary plenum sizes were investigated which, along with the standard 1T plenum, gave plenum volume-to-test section volume ratios of approximately 0.8, 1.8, 3.0, and 8.3.

SECTION II
APPARATUS

2.1 TUNNEL

Tunnel 1T is a continuous-flow, nonreturn wind tunnel equipped with a two-dimensional, flexible nozzle and an auxiliary plenum evacuation system. The Mach number range is normally from 0.2 to 1.5 utilizing variable nozzle contours above M = 1.1. For the present study, the nozzle was fixed on the sonic contour because the proposed modification to Tunnel A will have a fixed sonic nozzle. Total pressure control is not available in Tunnel 1T, and the tunnel is operated at a stilling chamber total pressure of about 2850 psfa with a ±5-percent variation dependent

on tunnel resistance and ambient atmospheric conditions. The stagnation temperature can be varied from 80 to 120°F above ambient temperature as necessary to prevent visible condensation in the test region.

The Tunnel 1T test section is composed of four removable walls which form a test region 37.5 in. long and 12- by 12-in. in cross section. The top and bottom walls are supported by flexures at the nozzle exit and by screw actuators at the downstream end to provide for variation in wall angle. The walls were set at zero wall angle (walls parallel) for this investigation. The variable porosity test section walls can be set for porosities from 0 to 10 percent; however, the installation of the auxiliary internal plenums made it difficult to change the wall porosity during the test. Therefore, the wall porosity was set at 3 percent for this investigation.

The general arrangement of the tunnel and its associated equipment is shown in Fig. 3. A detailed description of the tunnel and its capabilities is given in Ref. 3, while details of the variable porosity walls are given in Refs. 4 and 5.

2.2 PLENUM

The effective plenum volume was varied by the use of three removable auxiliary plenums installed inside the regular 1T plenum. The distance between the test section wall and the plenum wall was 2 in. for the small internal plenum, 4 in. for the medium internal plenum, and 6 in. for the large internal plenum. The small plenum simulated the plenum depth ratio desired for the proposed Tunnel A insert. The internal plenums exhausted to the regular 1T plenum at the rear of the test section. The internal plenums for each wall of the test section were not interconnected except through the regular 1T plenum. The regular 1T plenum has a circular cross section 41.25 in. in diameter.

The large internal plenum consisted of a 24-in.-square aluminum box built around the test section. The medium internal plenum was formed by installing 2-in. filler blocks inside the large internal plenum. The stringers of the variable porosity walls were deeper than the 2 in. required for the small plenum. Therefore, the small plenum was formed by bolting aluminum plates to the outside of the test section wall frames and using filler blocks to reduce the plenum depth to the required 2 in. Details of the internal plenums are shown in Fig. 4.

2.3 STATIC PRESSURE PIPE

A 1-in.-diam static pressure pipe was used to obtain the centerline static pressure distributions from Tunnel Station -2.6 to 34.4. The pipe has a total of 41 orifices which are spaced 2 in. apart from Station -8.6 to 3.4 and 1 in. apart from Station 3.4 to 37.4; however, not all orifices were used during this investigation because of an insufficient number of manometer tubes. The pipe attaches to the model sting support strut in the rear of the test section and extends into the stilling chamber. The installation is shown in Fig. 5.

2.4 CONE-CYLINDER MODEL

A sketch of the 20-deg cone-cylinder model showing the pressure orifice locations is given in Fig. 6. Through fabrication error, the cone angle was 18 minutes less than originally intended. An installation sketch is given in Fig. 7, and a photograph of the installation is presented in Fig. 8. The tunnel blockage of the cone-cylinder model was 1 percent.

The model orifices were relatively small, 0.023 in., and it was difficult to remove the burrs resulting from final machining. The data from a few of the orifices are not presented because of consistently high or low pressure measurements which were attributed to these burrs.

2.5 AGARD CALIBRATION MODEL B

The AGARD Calibration Model B is an ogive-cylinder with a delta wing. The specifications for the model are given in Ref. 6. The basic dimensions of the model are given in Fig. 9, and details of the installation are presented in Fig. 10. The tunnel blockage with the model at zero angle of attack was 2.5 percent.

2.6 INSTRUMENTATION

Model, static pipe, tunnel total, and auxiliary internal plenum pressures were photographically recorded from a multitube mercury manometer board referenced to the standard tunnel plenum pressure. Selected pressures were also measured by six precision pressure balance transducers for on-line monitoring. The standard tunnel plenum chamber reference pressure was measured with a servo-driven mercury manometer. The tunnel total temperature was measured by an iron-constantan thermocouple and displayed on an indicating potentiometer-type recorder.

Model forces on the AGARD Model B were measured with a six-component, internal, strain-gage balance. The dynamic outputs of the balance were monitored with an oscillograph to prevent overloading of the balance. The base pressures were measured by a 5-psi precision pressure balance transducer referenced to the standard tunnel plenum static pressure. Model force data were recorded on paper tape for off-line data reduction.

The influence of the size of the plenum volume on the magnitude and frequencies of the fluctuating pressures in the test section was also considered. In order to evaluate this possible influence, microphones were installed in the stilling chamber, in the test section wall immediately downstream of the nozzle exit, in the internal plenum, and in the standard plenum. The stilling chamber microphone was mounted approximately 8.5 in. from the tunnel shell, facing upstream. A screened protective nose was installed to protect the diaphragm. The test section microphone was installed with the diaphragm flush with the wall. The plenum chamber microphones were installed in the forward region of each plenum in areas that were expected to have relatively low flow velocities. In order to evaluate the vibration sensitivity of the microphones, accelerometers were integrally mounted with the stilling chamber and test section wall microphones. The locations of the test section and internal plenum microphones are shown in Fig. 4.

The output of each microphone and accelerometer was measured on-line using a root-mean-square (rms) voltmeter and recorded on magnetic tape, using an FM tape recorder, for an off-line spectrum analysis. In order to ensure the maximum signal-to-noise ratio of the dynamic data, selectable gain, decade amplifiers were included in the signal conditioning instrumentation. A dynamic calibration was performed on each channel prior to the day's test run. All dynamic calibrations were at a center frequency of 1×10^3 Hz. The microphones were calibrated with a precision acoustic calibrator at magnitudes that were representative of the tunnel operating levels. The accelerometers were calibrated electrically using the sensitivity most recently determined by the Calibration Laboratory. The frequency passband of the dynamic instrumentation was 50 Hz to 10 kHz; the upper cut-off frequency was determined by the magnetic tape recorder.

SECTION III
PROCEDURE

3.1 TEST CONDITIONS

The tests were conducted over the Mach number range from 0.6 to 1.3. The stagnation pressure varied from 2775 to 2990 psfa. The stagnation temperature was maintained at temperatures from 135 to 165°F as required to prevent moisture condensation in the test section. The nozzle was set on the sonic nozzle contour for all Mach numbers. All data were obtained with parallel test section walls set at a porosity of 3 percent.

3.2 TEST DISCUSSION

The test was conducted in three phases. In the first phase, tunnel calibration data and tunnel centerline Mach number distributions were obtained for the three auxiliary plenum configurations. In the second phase, the static pressure distributions on a 20-deg cone-cylinder model were obtained to investigate the effects of plenum chamber volume variations on the ability of the perforated walls to eliminate compression and expansion wave reflections from the test section walls. In the third phase, force and moment data on an AGARD Model B calibration model were obtained to investigate the effects of plenum volume variations on model force data.

The fluctuating dynamic pressures were measured during the static pipe and cone-cylinder phases of the test. Following the establishment of the desired steady-state tunnel conditions, the overall rms levels were measured at each microphone and accelerometer position, and a 30-sec record was taken on magnetic tape.

The evaluation of the air-on fluctuating pressures required that the no-flow acoustic disturbances, the vibration induced disturbances, and finally the instrument noise levels be evaluated. To accomplish this, three so-called background runs were established, and rms and magnetic tape data were taken. For these three background conditions, the main tunnel valve (Valve No. 1) was closed, and thus there was no airflow in the test section. The first background condition was with the compressor and steam ejector on, and permitted the evaluation of flanking acoustic sources not associated with airflow. In addition, with the aid of the accelerometers, the evaluation of structural inputs to the microphones was also possible. The second background was with the compressor on and the

steam ejector off. This allowed a crude evaluation of the acoustic disturbances contributed by the compressor. The third background condition was with both the steam and the compressor off. This allowed the evaluation of the minimum noise or instrument noise levels.

Based on the rms measurements, it was found that, for Background No. 1, the acoustic levels were 30 to 60 times below the minimum air-on levels. Correspondingly, the vibration levels were reduced by less than a factor of ten. For Background No. 2, the acoustic levels were further reduced by a factor of about two, and there was no decrease in the vibration levels. For Background No. 3, the acoustic and the vibration levels were both reduced by a factor of greater than 100 from the minimum air-on levels. Thus, it is concluded that the air-on measurements are representative of flow-induced disturbances and are not influenced by flanking acoustic transmission paths, vibration, or instrument noise.

3.3 DYNAMIC DATA REDUCTION

As mentioned in Section 2.6, the outputs of the microphones and accelerometers were measured using an rms voltmeter and were also recorded on magnetic tape for future analysis. Because of the length of time required for a comprehensive spectrum analysis, only the rms data are presented in this report. The rms data were corrected for the calibration and background values.

3.4 PRECISION OF MEASUREMENTS

The estimated uncertainties in the data which can be attributed to instrumentation errors and data acquisition techniques are presented below. The uncertainties were determined for a confidence level of 95 percent.

M_∞	0.60	1.00	1.2
C_L	±0.0015	±0.0008	±0.0007
C_m	±0.0111	±0.0061	±0.0054
C_D	±0.0013	±0.0011	±0.0010
$C_{D,b}$	±0.0008	±0.0005	±0.0005
$\Delta p/p_t$	±0.003	±0.003	±0.003
p/p_t	±0.003	±0.003	±0.003
M_∞	±0.0035	±0.0035	±0.0035
α	±0.1	±0.1	±0.1
τ	±0.15	±0.15	±0.15
2σ	±0.0018	±0.0018	±0.0018

SECTION IV
RESULTS

4.1 CENTERLINE MACH NUMBER DISTRIBUTIONS

Representative test section centerline Mach number distributions obtained with the standard 1T plenum (Ref. 4) and with the three auxiliary internal plenums installed in the tunnel are presented in Fig. 11. Variations in plenum volume had no measurable effects on the test section centerline Mach number distribution for Mach numbers below 0.95, and are, therefore, not presented. The 2σ Mach number deviations between Stations 12.4 and 30.4 for all plenum configurations are presented in Fig. 12. At Mach numbers above 0.95, decreasing the plenum volume increased the 2σ Mach number deviations when compared with the standard 1T plenum. The 2σ Mach number deviations for the large and medium size plenums were approximately the same magnitude at all Mach numbers. The 2σ Mach number deviations for the small plenum were greater than the other internal plenums at Mach number above 0.95. The increase in the 2σ Mach number deviation for the small plenum is primarily the result of a perturbation in the Mach number distribution near Tunnel Station 20. The cause of this increase is not known. The test section wall does have a transverse frame near this location; however, no significant Mach number deviations were noted at the locations of other transverse frames (Stations 7, 14, and 27).

Decreasing the plenum volume also increased the plenum suction required to establish the desired test section Mach number at Mach numbers above 1.0. Static pressure measurements on the bottom walls of the internal plenums revealed that the increased suction requirements were caused by a static pressure gradient along the length of the plenum (Fig. 13). The static pressure gradient increased with decreasing plenum volume and was attributed to the increased friction losses associated with the increased velocity required inside the plenum as the plenum volume was reduced. This static pressure gradient produced an increase in the local Mach number aft of Tunnel Station 30 for Mach numbers above 1.15.

It should be noted that the internal plenums were open to the regular tunnel plenum at the rear of the test section only. This required the entire mass flow that was being removed through each wall to pass through the openings at the rear of the internal plenums. Most of the mass flow removal through the walls occurs ahead of Station 14 at Mach numbers above 1.0. Therefore, removing the auxiliary plenum flow in the vicinity of tapered porosity region should reduce the flow inside the plenum shell aft of Station 14 and improve the Mach number distribution.

4.2 CONE-CYLINDER PRESSURE DISTRIBUTIONS

The pressure distributions on a 1-percent blockage, 20-deg, cone-cylinder model were measured to determine the effect of plenum volume on the wave-cancellation properties of perforated walls. The pressure distributions of the cone-cylinder model can be better understood with the aid of Fig. 14. The initial reflections from the bow shock and the shoulder expansion fan on the model will impinge upon the model at the approximate stations shown. If the wall possesses the desired wave cancellation characteristics, the model pressures will show no perturbations at these specific body stations. If the wall is too open, then the bow shock will be reflected as an expansion wave and the shoulder expansion fan will be reflected as a shock wave. If the wall is too solid, the bow shock will reflect as a shock wave and the shoulder expansion fan will reflect as expansion waves.

The model pressure distributions for the standard 1T plenum (Ref. 5) and the three auxiliary plenum configurations are compared in Fig. 15 with interference-free curves that are based on theory and on empirical results from Refs. 7 and 8. The error in cone angle results in a corresponding error in the interference-free pressure ratio of less than 0.002, which is considered to be insignificant.

The interference-free data were available at discrete Mach numbers only, whereas the Mach number at which the present wind tunnel data were obtained deviated from the nominal values as much as $\Delta M = 0.010$ for the large and medium plenum configurations. The deviation from the nominal Mach number for the small plenum was also less than 0.01 for Mach numbers up to $M_\infty = 1.05$. At higher Mach numbers, the desired Mach number was difficult to set with the small plenum because of the amount of plenum suction required to establish test conditions. Data presented in Fig. 15e for the small plenum at a nominal Mach number of 1.15 were actually obtained at $M_\infty = 1.172$, and no data for the small plenum were obtained at a Mach number close enough to 1.20 to be used for comparison with the interference-free curves. Data for the cone-cylinder models using the standard 1T plenum configuration were obtained prior to the tunnel calibration with the variable porosity walls (Ref. 4), and the Mach number for these data may vary as much as 0.03 from the nominal value.

The data indicate that decreasing the plenum volume produces a slight increase in the effective wall porosity. This is most evident at a Mach number of 1.10 where the bow wave reflects as a very weak expansion wave in the vicinity of $x/d = 4$. The reflected bow wave produces a slight increase in the pressure ratio that gets stronger with decreasing plenum size. The disturbance from the reflected shoulder wave near $x/d = 7$ also increases slightly with decreasing plenum volume at these Mach numbers. If the wall porosity were reduced, these effects would probably disappear.

4.3 AGARD CALIBRATION MODEL B FORCE DATA

The lift, drag, and pitching-moment characteristics of the AGARD Model B were obtained at Mach numbers from 0.6 to 1.2 with the four plenum configurations. Typical force and moment data for selected Mach numbers using the standard 1T plenum data as a basis for comparison are presented in Figs. 16 through 20.

Considerable difficulty was experienced in obtaining good data because of problems with the model support system. After data had been obtained with the standard 1T plenum, the balance was found to be loose on the sting. Therefore, the runs with the standard plenum were repeated. When the data were reduced after testing had been completed, the data for the small plenum also showed evidence of a loose balance. A comparison of data obtained with and without the loose balance with the standard plenum configuration revealed that the only measurable effect of the loose balance was to decrease the effective angle of attack

for angles of attack below 3 deg. When the angle of attack was corrected by the amount necessary to give the correct lift coefficient at zero angle of attack, the data agreed within the accuracy of measurement. Therefore, the data obtained at angles of attack below 3 deg with the small plenum were corrected by the amount necessary to give the correct lift coefficient at zero angle of attack.

Decreasing the plenum volume had no effect on the aerodynamic coefficients except to increase the forebody drag coefficient at Mach numbers above 1.05 with the small plenum (Fig. 18a). The lift coefficient for the medium plenum was higher than for the small, large, and standard plenums at angles of attack above 3 deg for Mach numbers between 0.6 and 0.9. A bearing in the pitch mechanism failed while testing this configuration and was replaced prior to testing at $M_\infty = 0.95$. Therefore, it is felt that the angle of attack was incorrect at higher angles of attack for Mach numbers below 0.95 when the medium plenum was installed. The good agreement between the lift coefficients with the small and large plenums supports this conclusion.

The base drag values for the AGARD Model B with the three auxiliary internal plenums installed show much better agreement with each other than with the standard tunnel results. Since the base drags for the three internal plenums are in substantial agreement, there does not appear to be any significant effect of plenum volume on base drag.

4.4 ACOUSTIC DATA

The acoustic measurements were included during the plenum volume study to determine if the inherent cavity resonances of the various size plenums could influence the fluctuating pressures in the test section. Such an influence could limit the test capability of the proposed tunnel insert; particularly in the areas of buffet, flutter, and Magnus force testing.

As mentioned in Section 3.3, only the overall rms data are presented in this report. In addition, the rms data in the plenum cavities have not been presented because of the need for the spectrum analyses for the interpretation of the overall levels. Thus, discussion is limited to the data taken in the stilling chamber and in the test section.

The test section data are limited by the fact that the microphone was located on the wall and at the forward end of the test section rather than on the tunnel centerline and at a midpoint in the test section. This was necessary because the dynamic instrumentation had to be installed

in a manner that would not require extensive modification to the moving plate of the variable porosity walls. During the conduct of recent acoustic studies in Tunnel 16T, forward and midsection microphones were mounted on the test section wall, and two centerline microphones were installed in a 10-deg cone. The data from these microphones have been used to arrive at a qualitative assessment of what information can be derived from the 1-ft tunnel wall-mounted microphone. Based on this comparison, it appears that for low Mach numbers ($M_\infty \leq 0.85$) and for large disturbances ($\tilde{p} > 10.0$) the measurements at the forward location can be considered as representative of the free-stream levels. For $M_\infty > 0.85$, the measurements are low by a factor of 3 to 4. The explanation for this lower level is twofold: (1) the forward microphone is shielded from the test section disturbances as the velocity approaches $M_\infty = 1.0$ and (2) the flow conditions at the wall are relatively constant at the forward end of the test section while the need for plenum suction at the higher Mach numbers alters the flow at the midsection of the wall and raises the noise levels. Thus, the test section wall data are intended to show only the relative variations of test section noise levels as a function of plenum volume size.

A comparison of the measured rms levels in the stilling chamber and on the test section wall is shown in Fig. 21 for the three different internal plenum volumes and with the static pipe installed. Also, in Fig. 21b, selected points with the standard plenum volume are shown. These points were taken with the AGARD model installed, however, rather than the static pipe. It is noted in Fig. 21a that the stilling chamber levels are relatively constant as a function of auxiliary plenum size. Thus the stilling chamber can be considered as a constant acoustic source, and the measured variations in the test section can be attributed to the influence, either direct or indirect, of the auxiliary plenum volumes. As noted in Fig. 21b, this influence is slight except at low subsonic Mach numbers where the smaller volume shifts the maximum rms pressure to a lower Mach number. The same trends are repeated with the cone-cylinder model installed (Fig. 22). In both figures, the maximum level does not change significantly, only the Mach number at which it occurs. Thus based on the measured overall rms noise levels, there is no apparent penalty in using the smaller plenum volume.

SECTION V
CONCLUSIONS

An investigation of the effects of reducing plenum volume on transonic flow characteristics has been conducted in the PWT Aerodynamic

Wind Tunnel (1T). The basic purpose of the study was to determine the feasibility of a transonic insert proposed for the VKF Supersonic Wind Tunnel (A), which, to produce a transonic test section of reasonable size (30 by 30 in.), would have a necessarily small plenum volume ratio of approximately 0.8. The primary results of the tests, which are presented below, show in general, that only relatively small adverse effects were obtained for reductions in plenum-to-test section volume ratio from approximately 8.3 to 0.8. Since methods of improving the flow quality, such as a better plenum suction arrangement and variable porosity walls, can be incorporated in the insert design, it is concluded that the plenum insert is a very promising method for providing a transonic test capability in Tunnel A.

The following specific conclusions have been drawn from the results obtained:

1. Decreasing the plenum volume produced no measurable effects on the test section Mach number distribution at Mach numbers below 0.95. At Mach numbers above 0.95, decreasing the plenum volume increased the deviations in local Mach number; however, the deviations were small for Mach numbers up to 1.15. Slightly larger deviations were obtained with the small plenum than with the medium and large plenums.
2. Decreasing the plenum volume increased the plenum suction required to establish the desired test section Mach numbers at Mach numbers above 1.0.
3. Reducing the plenum volume produced a slight increase in the effective wall porosity.
4. Reducing the plenum volume had no effect on the lift, base drag, and pitching moment coefficients for the AGARD Calibration Model B. The forebody drag coefficient was observed to increase with decreasing plenum volume for Mach numbers above 1.0.
5. Reducing the plenum volume had no significant effects on the tunnel acoustics.

REFERENCES

1. Covert, Eugene E. "A Summary of Experiments with Slotted Transonic Inserts in the Naval Supersonic Laboratory Wind Tunnel." Massachusetts Institute of Technology, Naval Supersonic Laboratory, Technical Report 207, April 1958.

2. Tirumalesa, D. and Satyanarayana, B. "An Experimental Study of the Effects of the Plenum Chamber Size on the Flow in a Slotted Wall Transonic Test Section." Journal of the Aeronautical Society of India, Vol. 12, No. 3, August 1960.

3. "Propulsion Wind Tunnel Facility, Vol. 5." Test Facilities Handbook (Eighth Edition). Arnold Engineering Development Center, December 1969 (AD863646).

4. Jackson, F. M. "Calibration of the AEDC-PWT 1-Ft Transonic Tunnel with Variable Porosity Test Section Walls." AEDC-TR-69-114 (AD853073), May 1969.

5. Jacocks, J. L. "Reduction of Wall Interference Effects in the AEDC-PWT 1-Ft Transonic Tunnel with Variable Perforated Walls." AEDC-TR-69-86 (AD851575), May 1969.

6. "Specifications for AGARD Wind Tunnel Calibration Models." AGARD Memorandum AG-4/M3, August 1955.

7. Estabrooks, Bruce B. "Wall-Interference Effects on Axisymmetric Bodies in Transonic Wind Tunnels." AEDC-TR-59-12 (AD216698), June 1959.

8. Hartley, M. S. and Jacocks, J. L. "Static Pressure Distributions on Various Bodies of Revolution at Mach Numbers from 0.69 to 1.60." AEDC-TR-68-37 (AD828571), March 1968.

APPENDIX
ILLUSTRATIONS

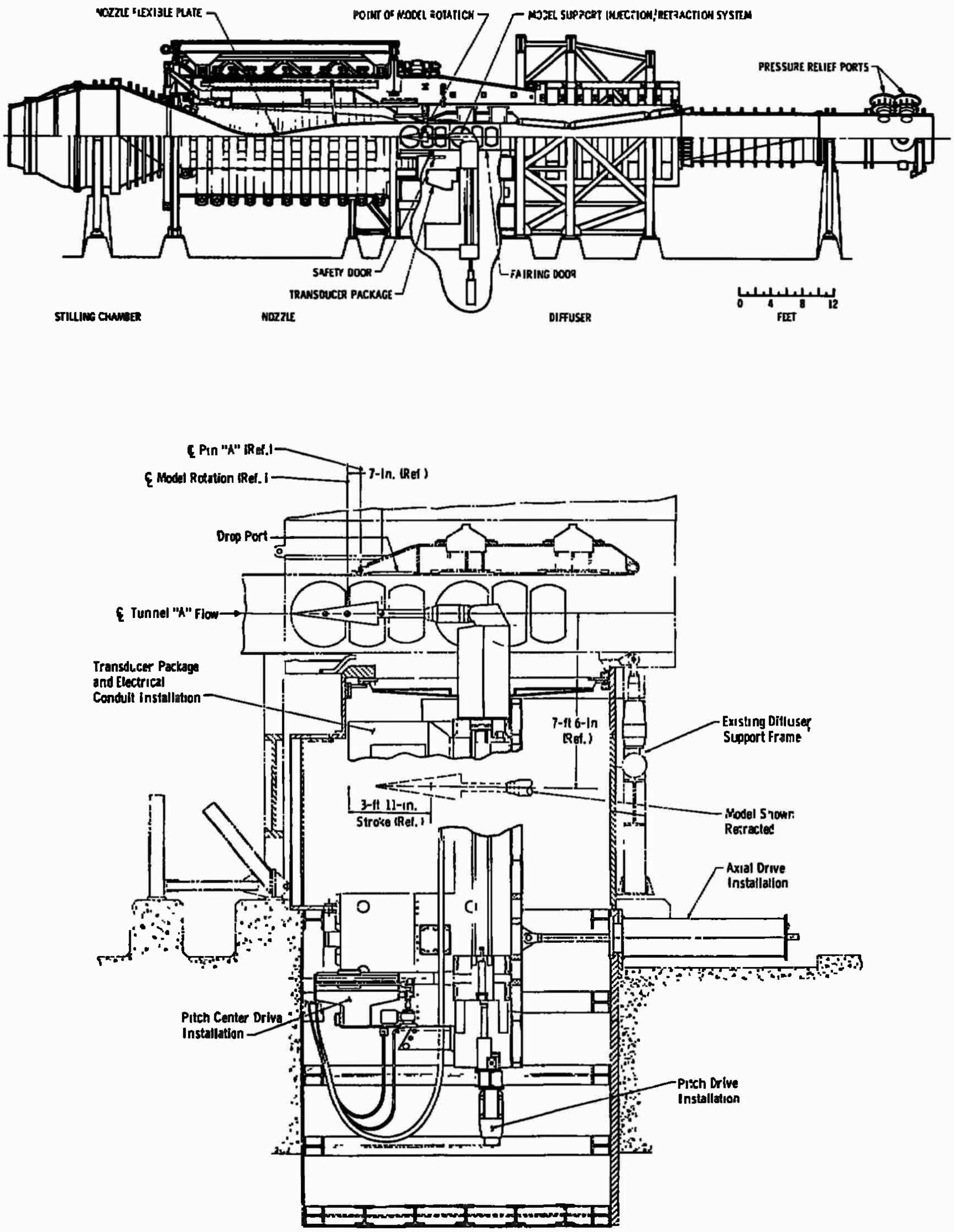


Fig. 1 General Arrangement of VKF Tunnel A

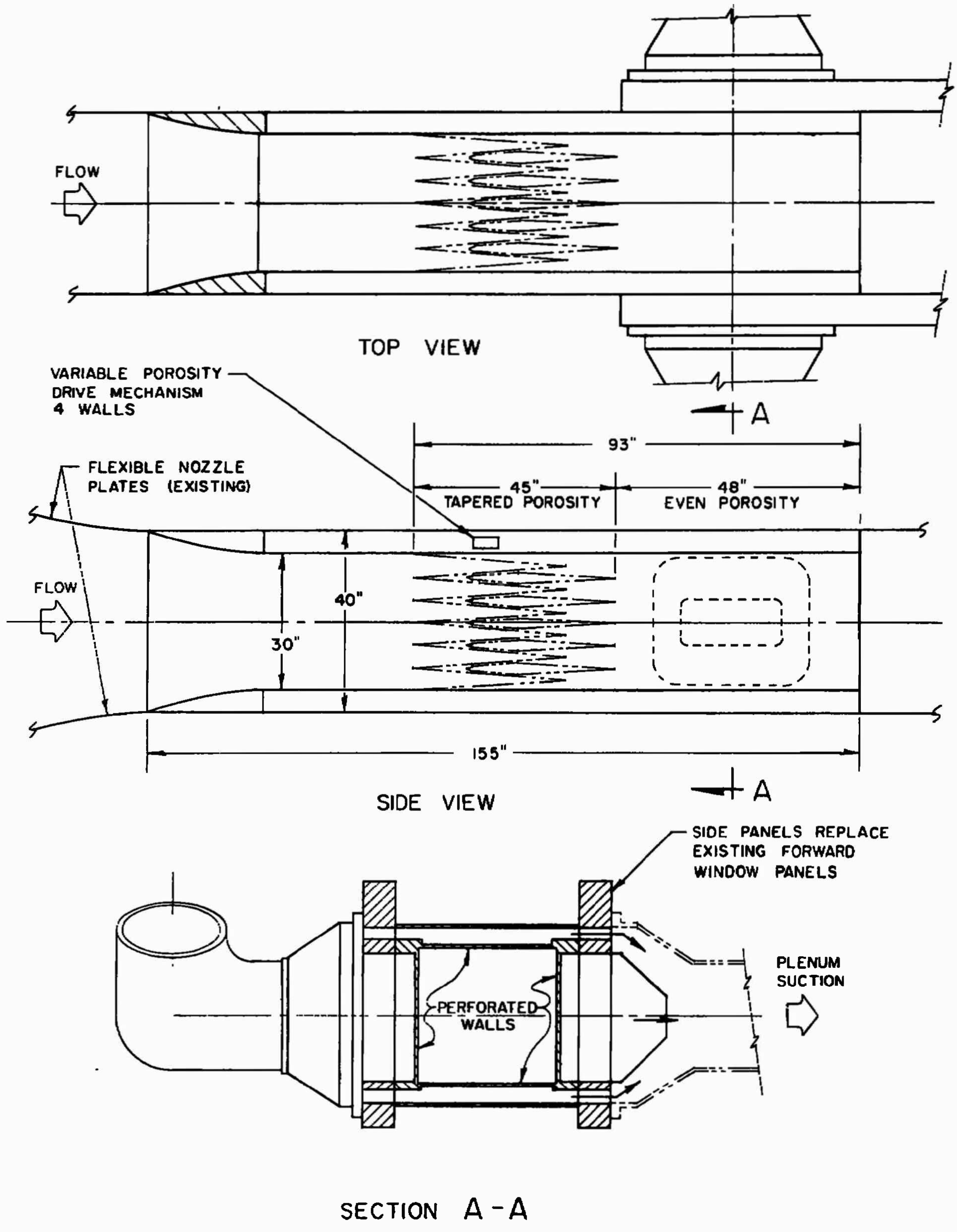


Fig. 2 Tunnel A Plenum Insert Schematic

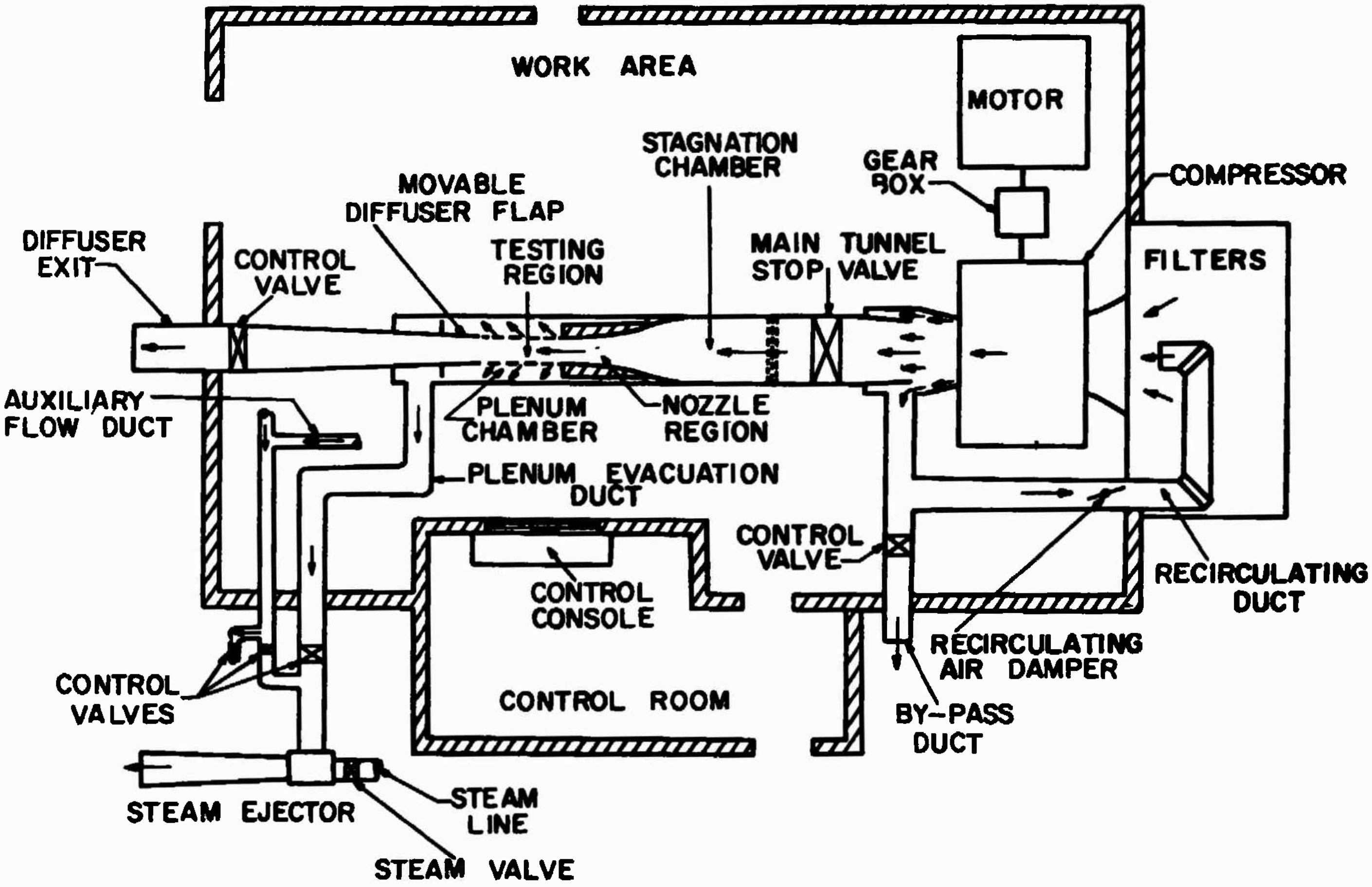
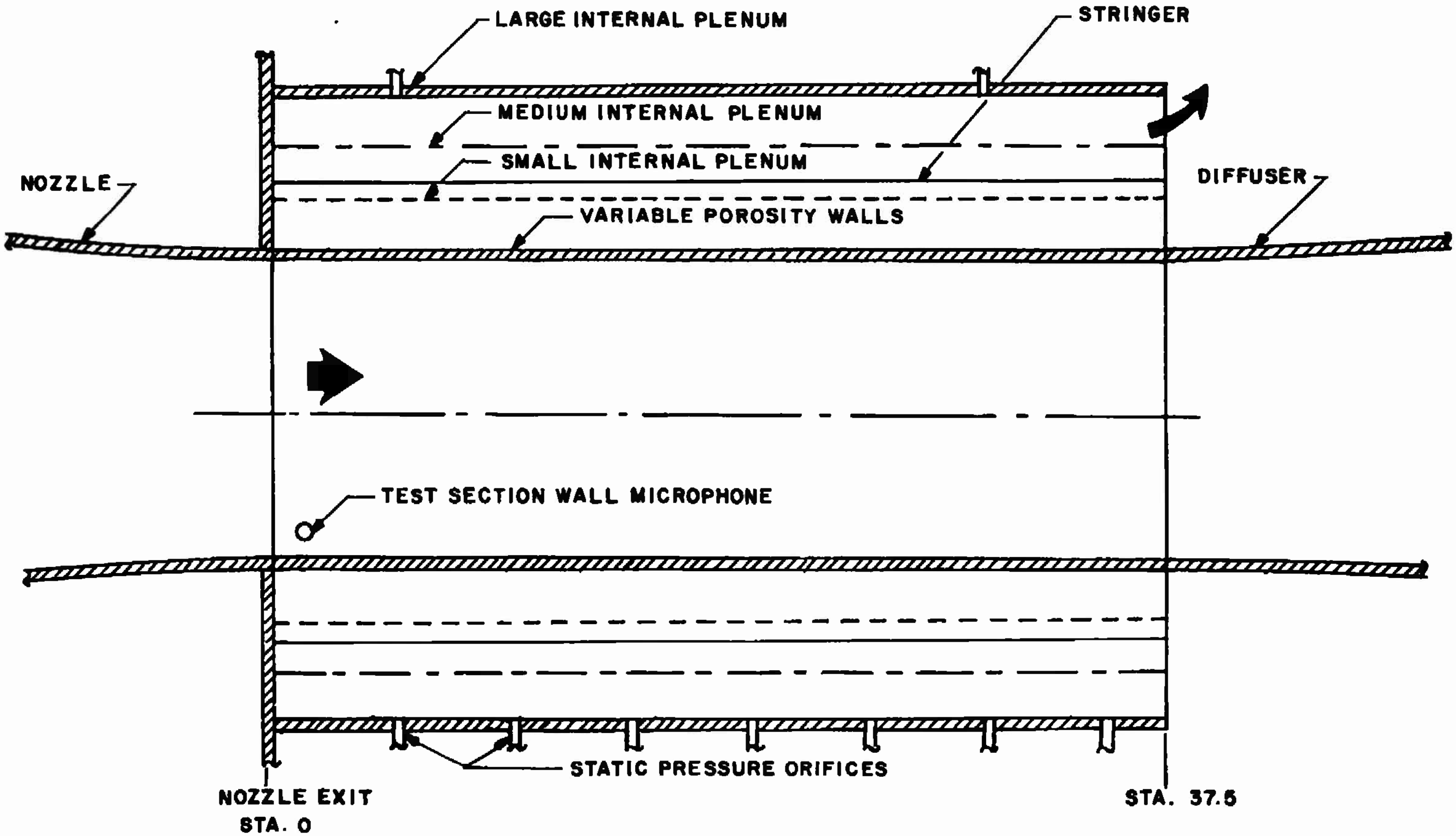


Fig. 3 General Arrangement of Tunnel 1T and Supporting Equipment

NOTE:

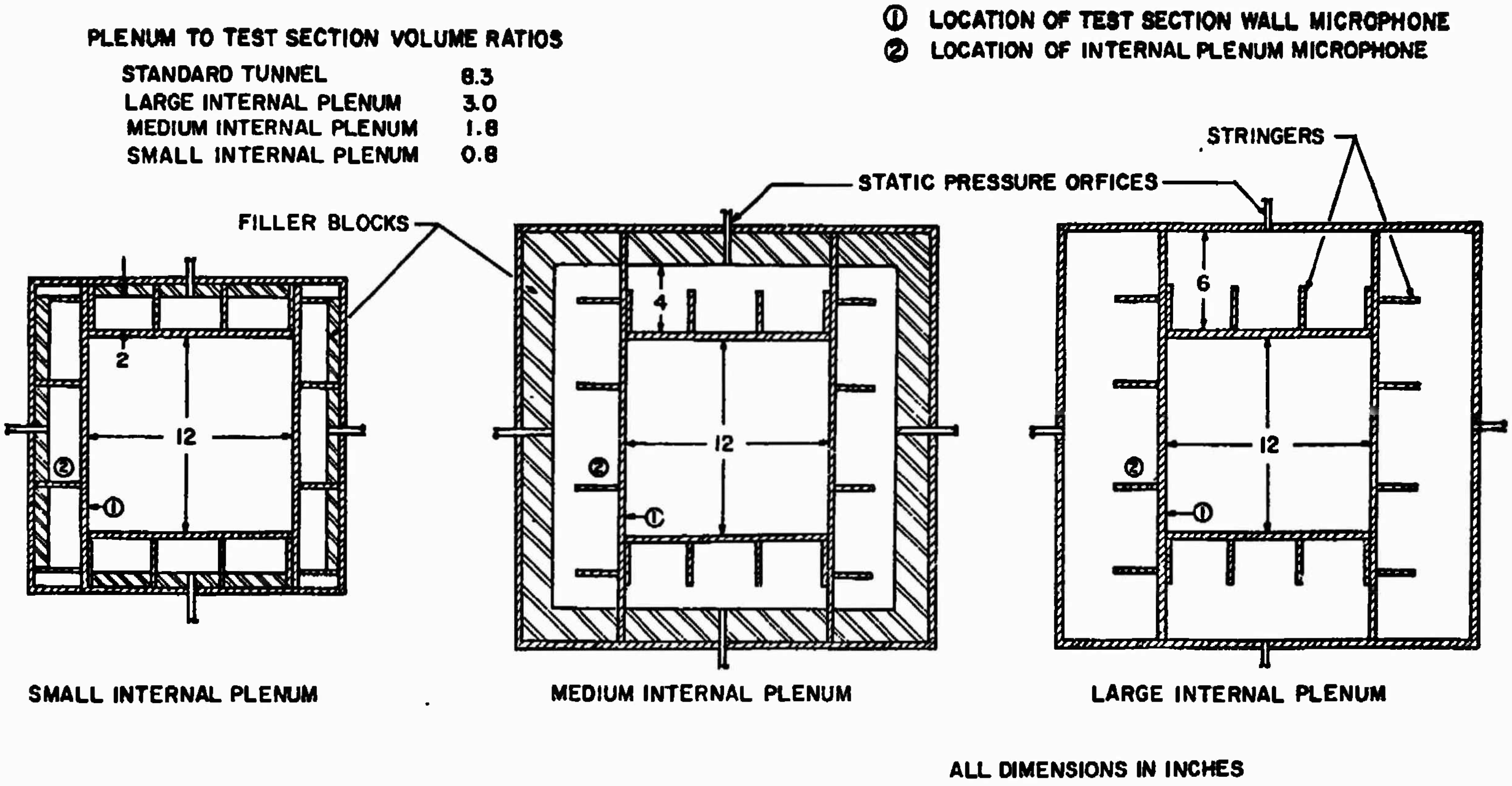
PLENUM WALL STATIC PRESSURE ORIFICES WERE INSTALLED AT 5 INCH INTERVALS BETWEEN STATIONS 5 AND 35 ON THE BOTTOM WALL AND AT STATIONS 5 AND 30 ON THE OTHER WALLS

ALL DIMENSIONS IN INCHES



a. Side View

Fig. 4 Internal Plenums



b. Cross-Section View
Fig. 4 Concluded

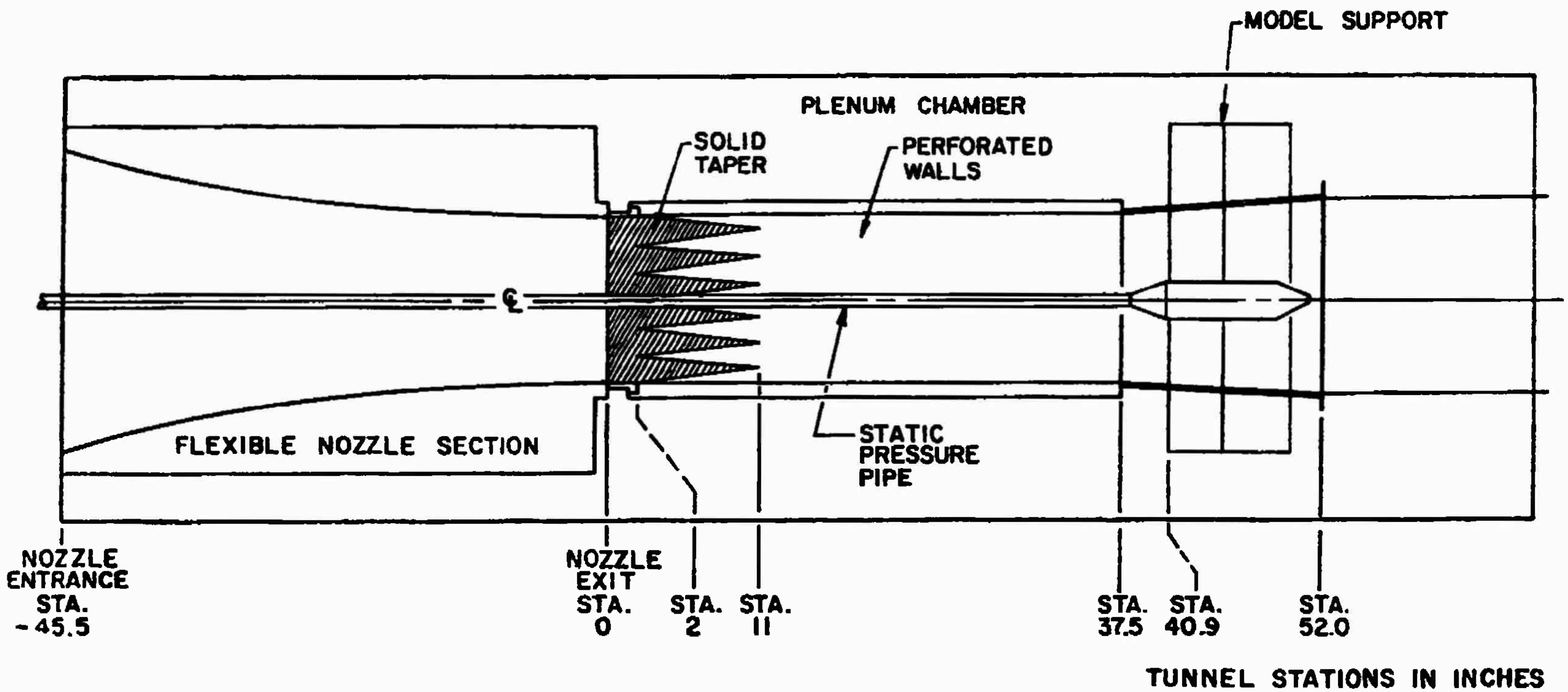
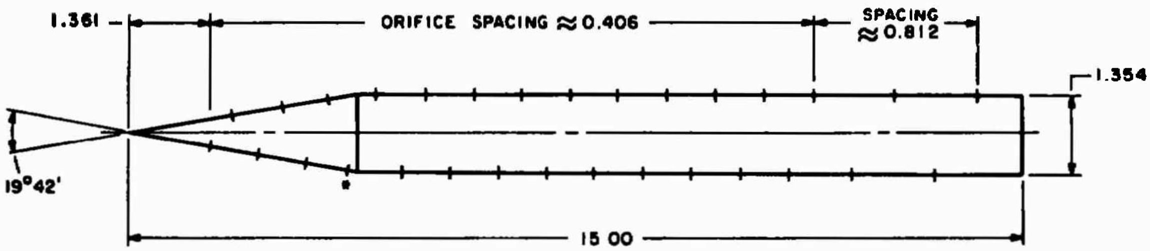


Fig. 5 Static Pressure Pipe Installation



ORIFICE LOCATIONS

BOTTOM ROW NO	x/d	TOP ROW NO	x/d
1	1.005	2	1.304
3	1.606	4	1.905
5	2.205	6	2.504
7	2.699	8	3.095
9	3.398	10	3.700
11	3.999	12	4.300
13	4.598	14	4.900
15	5.199	16	5.498
17	5.798	18	6.099
19	6.397	20	6.699
21	6.999	22	7.299
23	7.600	24	7.901
25	8.198	26	8.498
27	8.997	28	9.500
29	9.996	30	10.496

Fig. 6 Sketch of 20-deg Cone-Cylinder Model

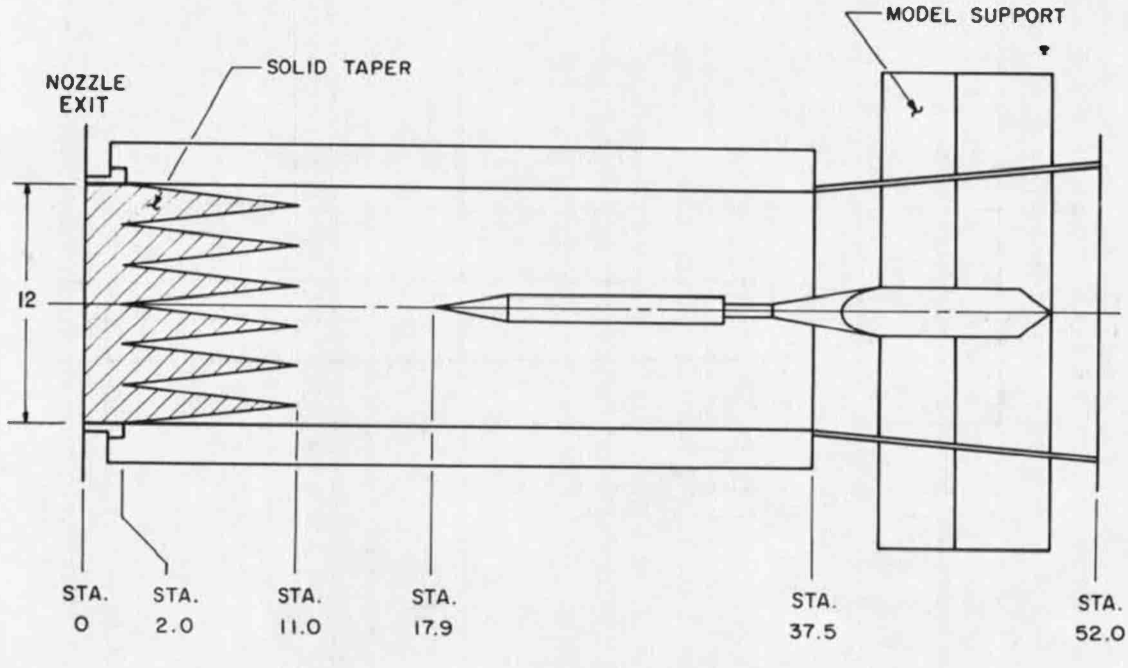


Fig. 7 Cone-Cylinder Pressure Model Installation

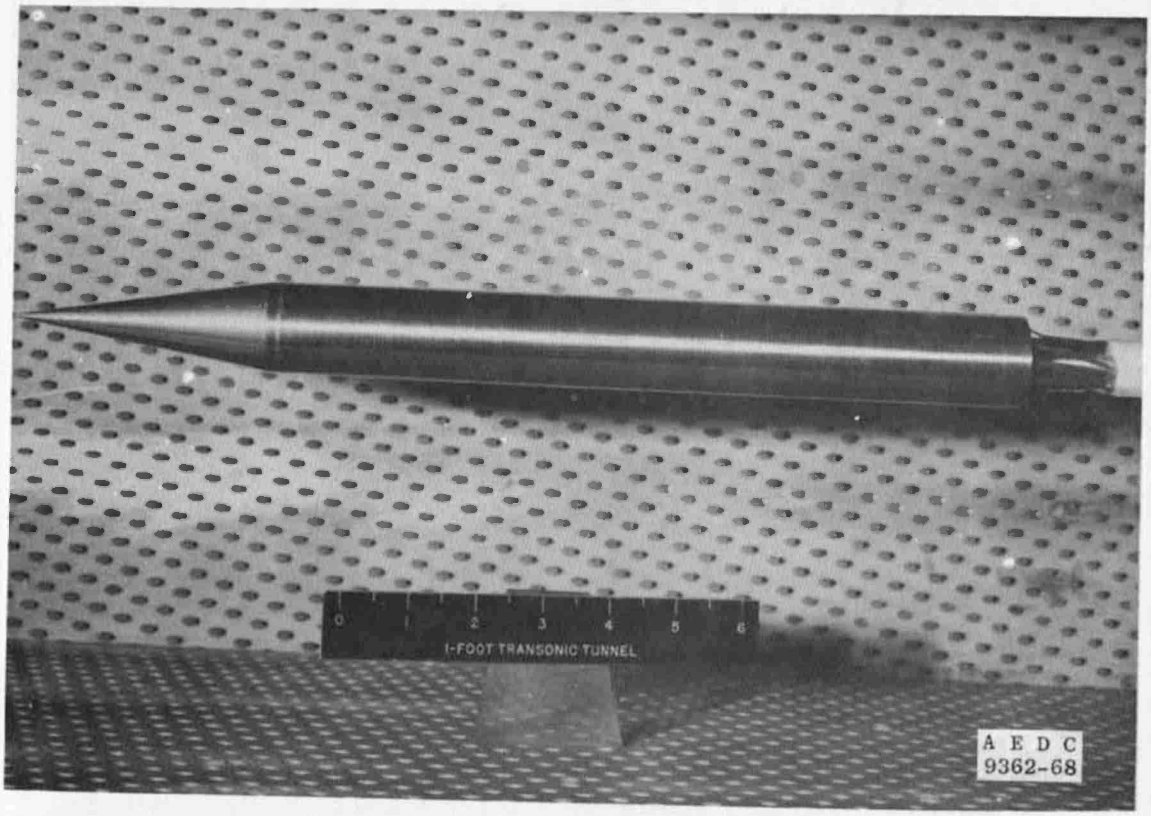
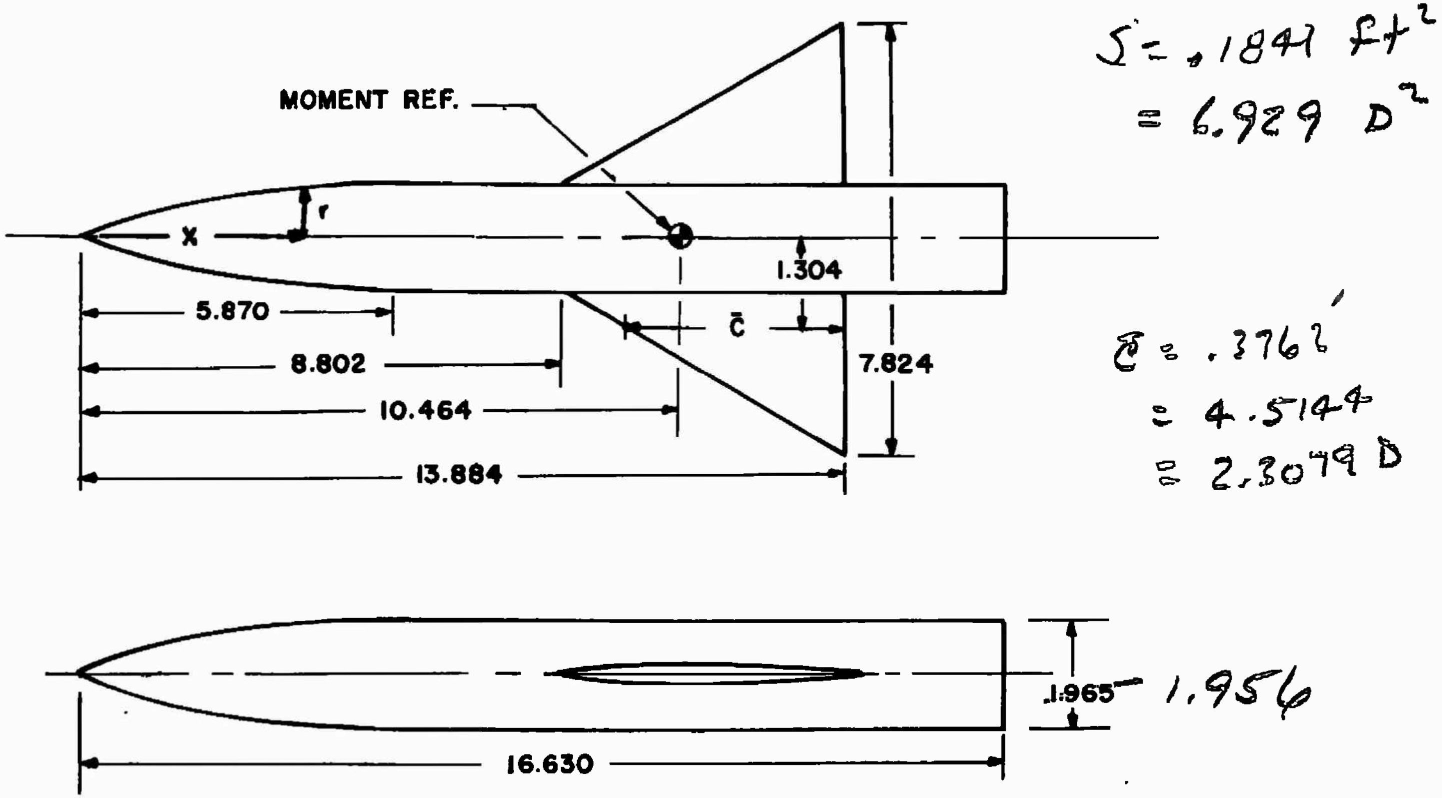


Fig. 8 Photograph of 20-deg Cone-Cylinder Model Installation

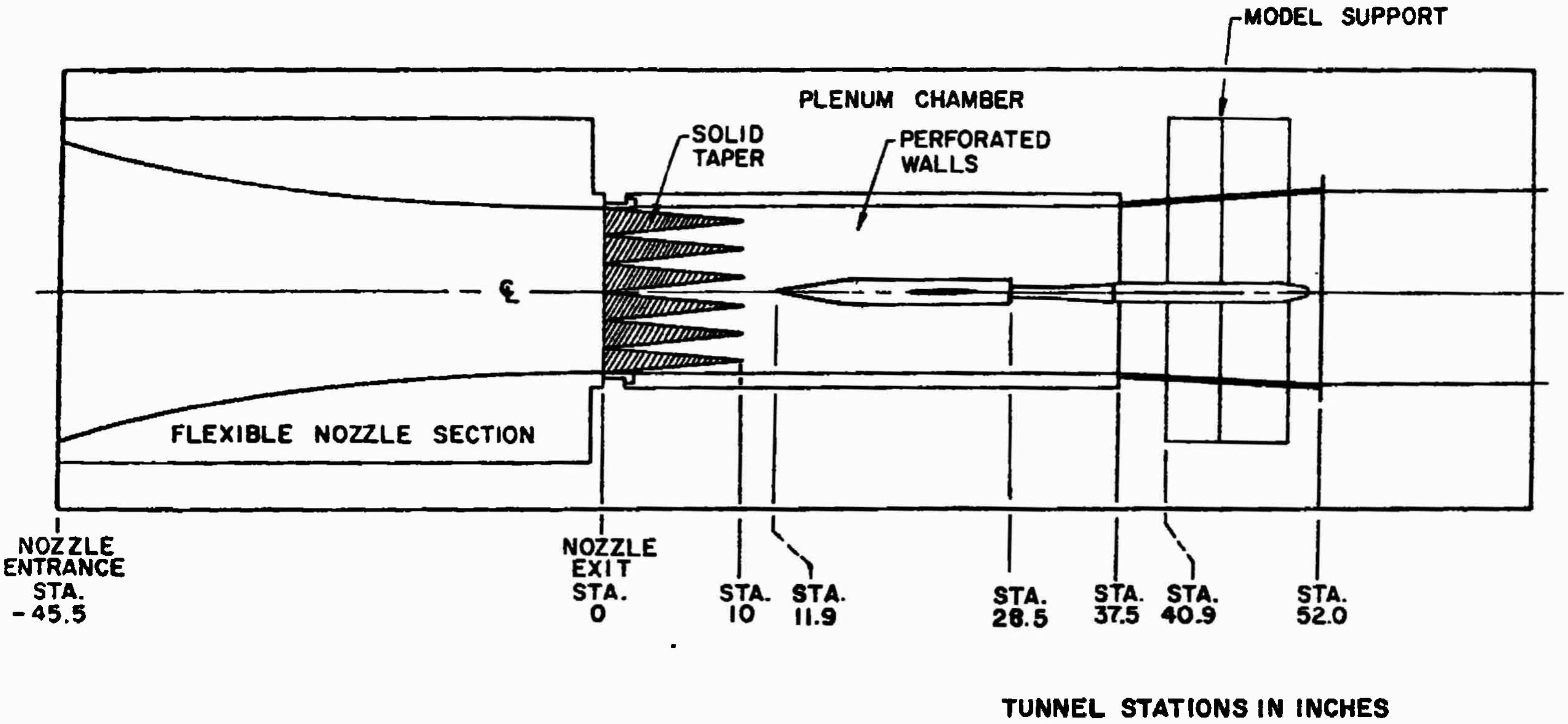
$$r = \frac{x}{3}\left[1 - \frac{1}{9}\left(\frac{x}{1.956}\right)^2 + \frac{1}{54}\left(\frac{x}{1.956}\right)^3\right]$$

AIRFOIL SYMMETRICAL
4 % CIRCULAR ARC



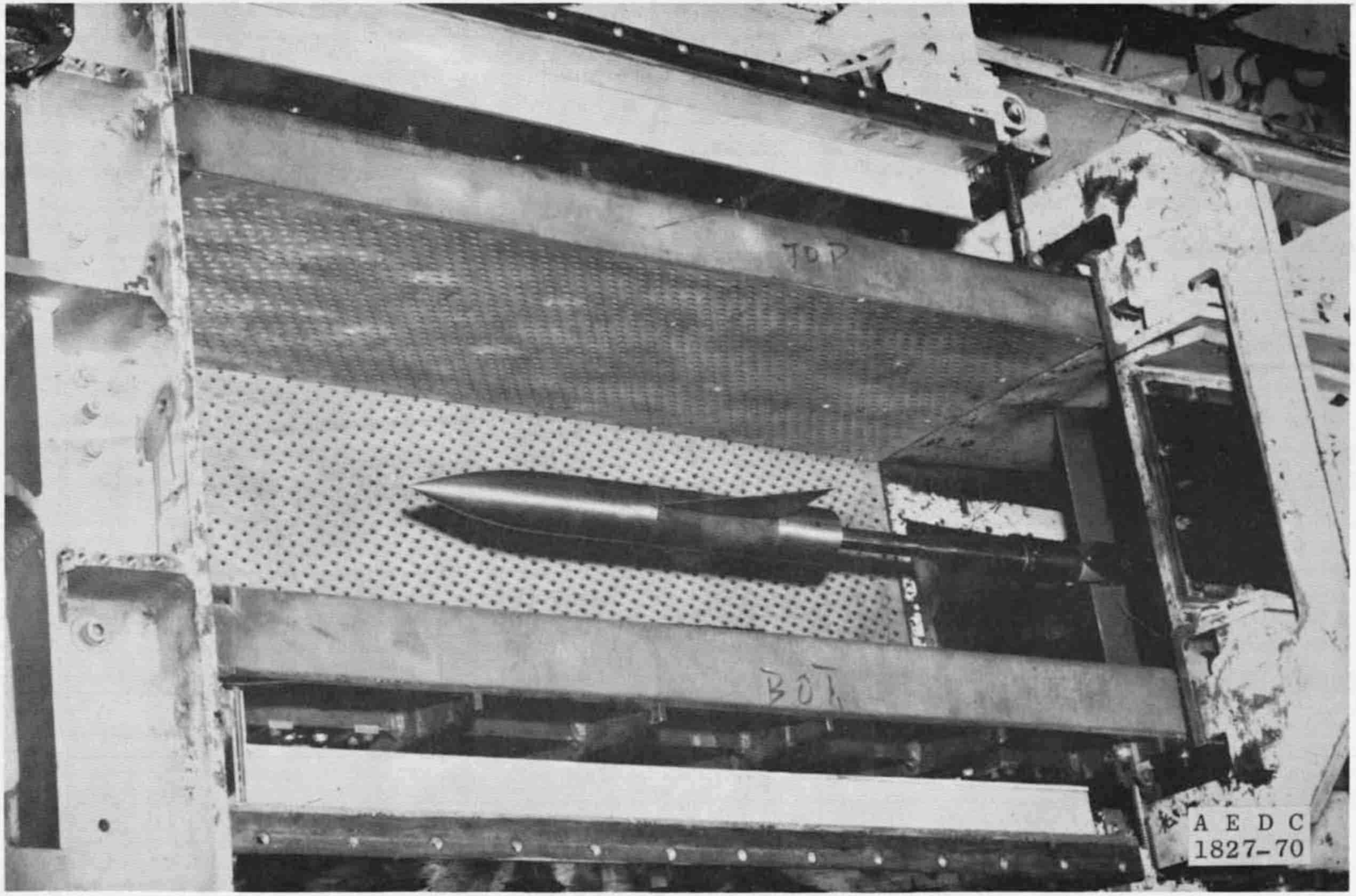
ALL DIMENSIONS IN INCHES

Fig. 9 AGARD Calibration Model B

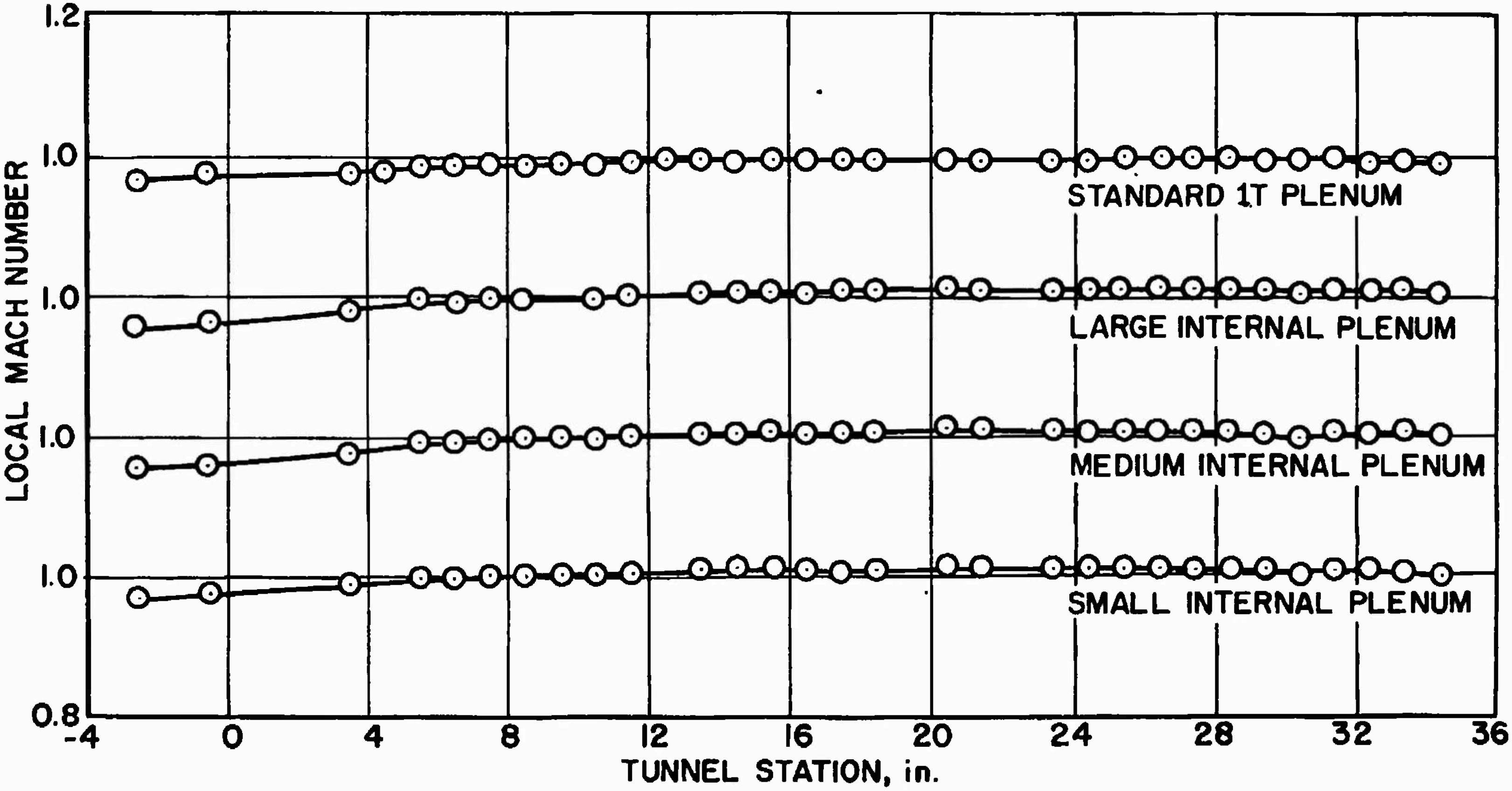


a. Model Location

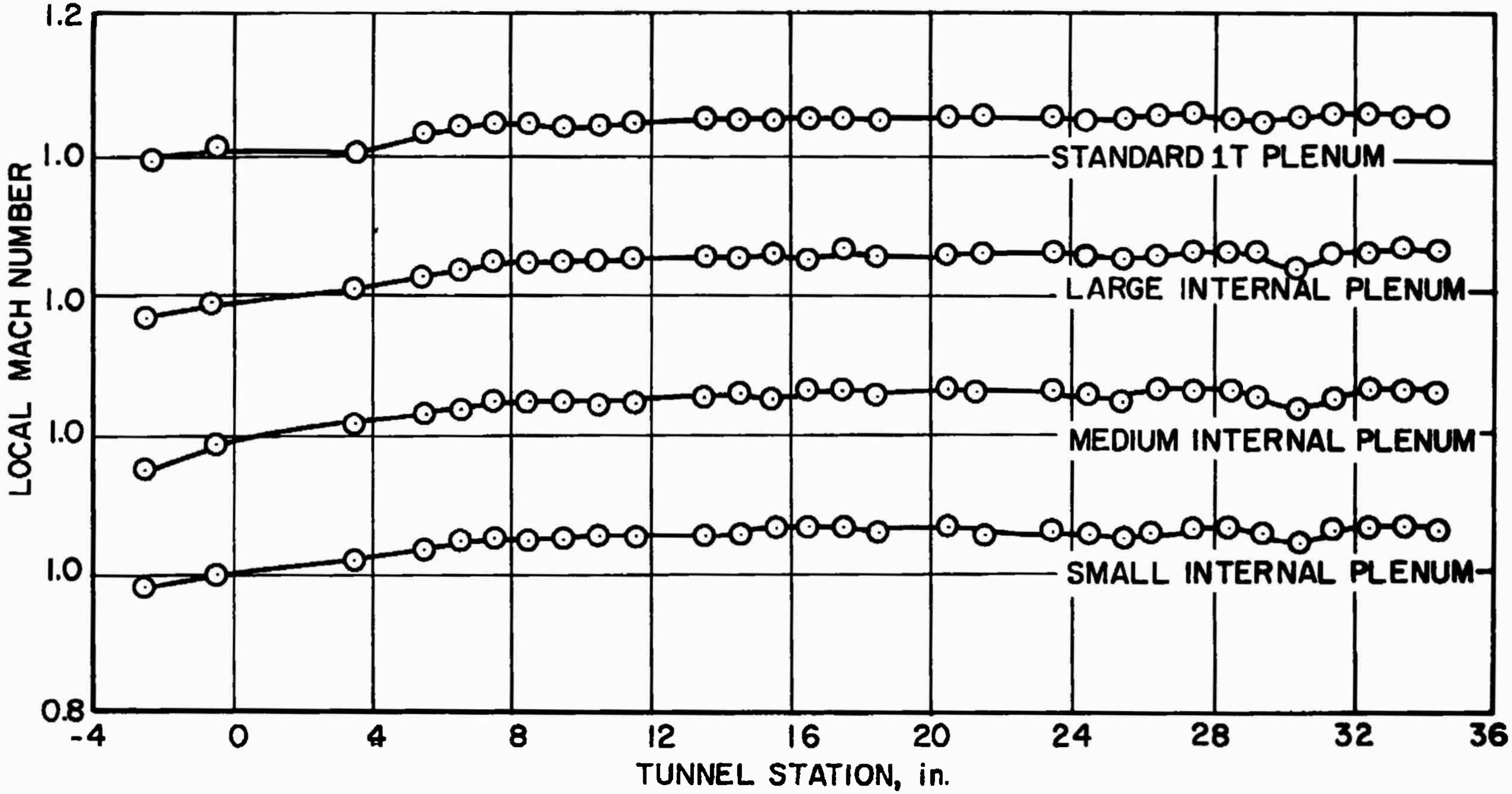
Fig. 10 AGARD Calibration Model B Installation



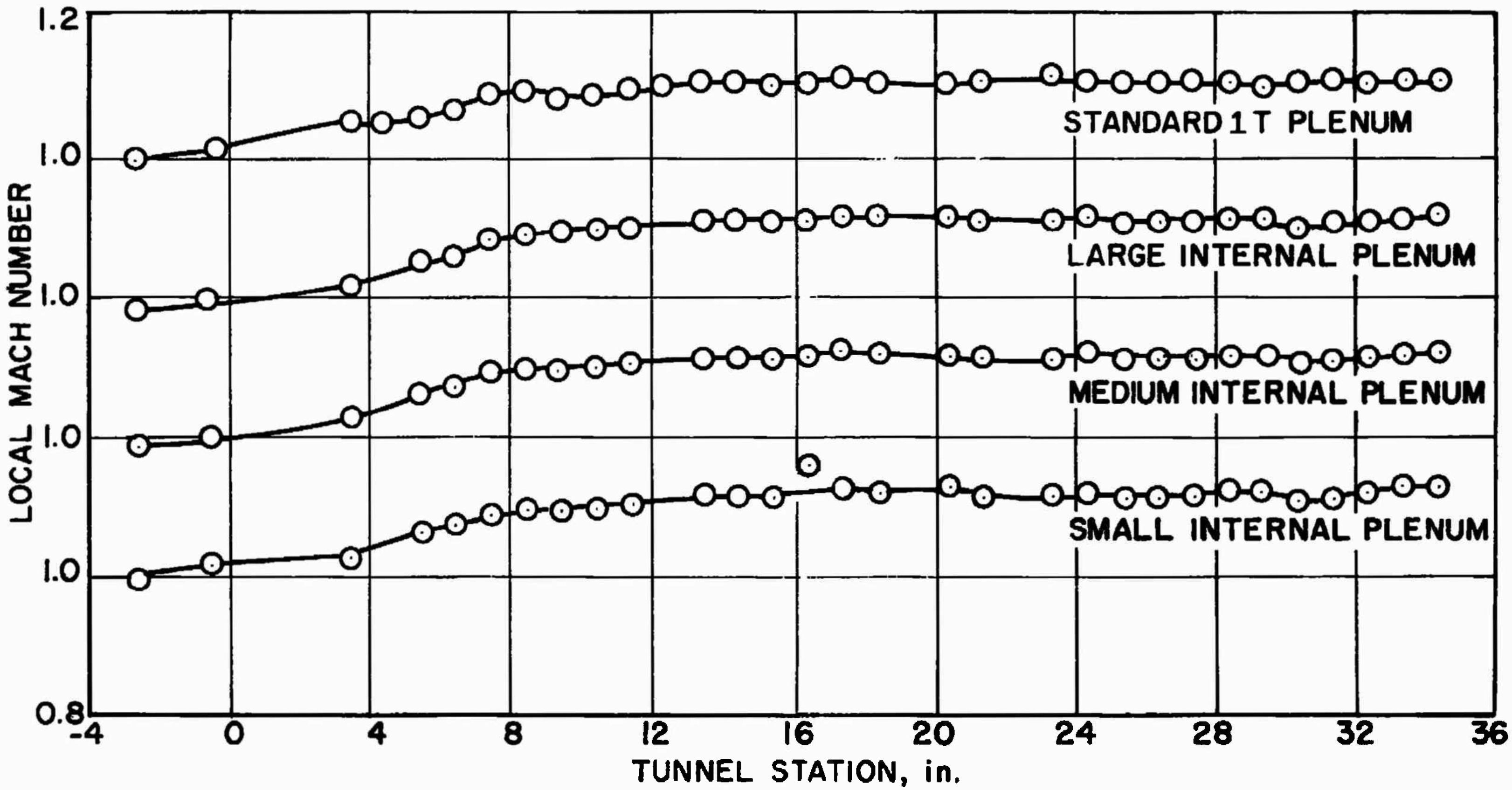
b. Photograph of Model
Fig. 10 Concluded



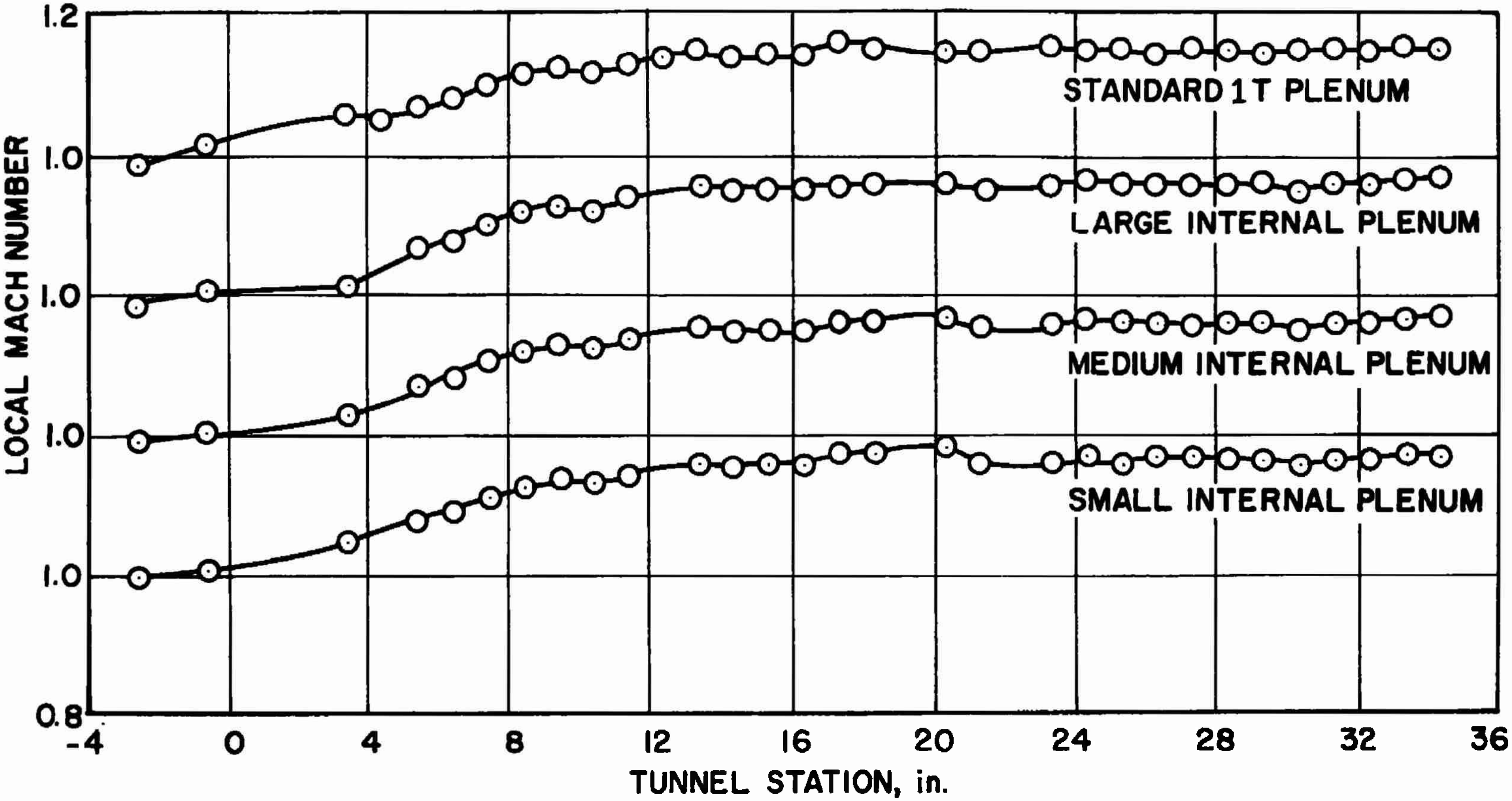
a. $M_\infty = 1.00$
Fig. 11 Centerline Mach Number Distributions



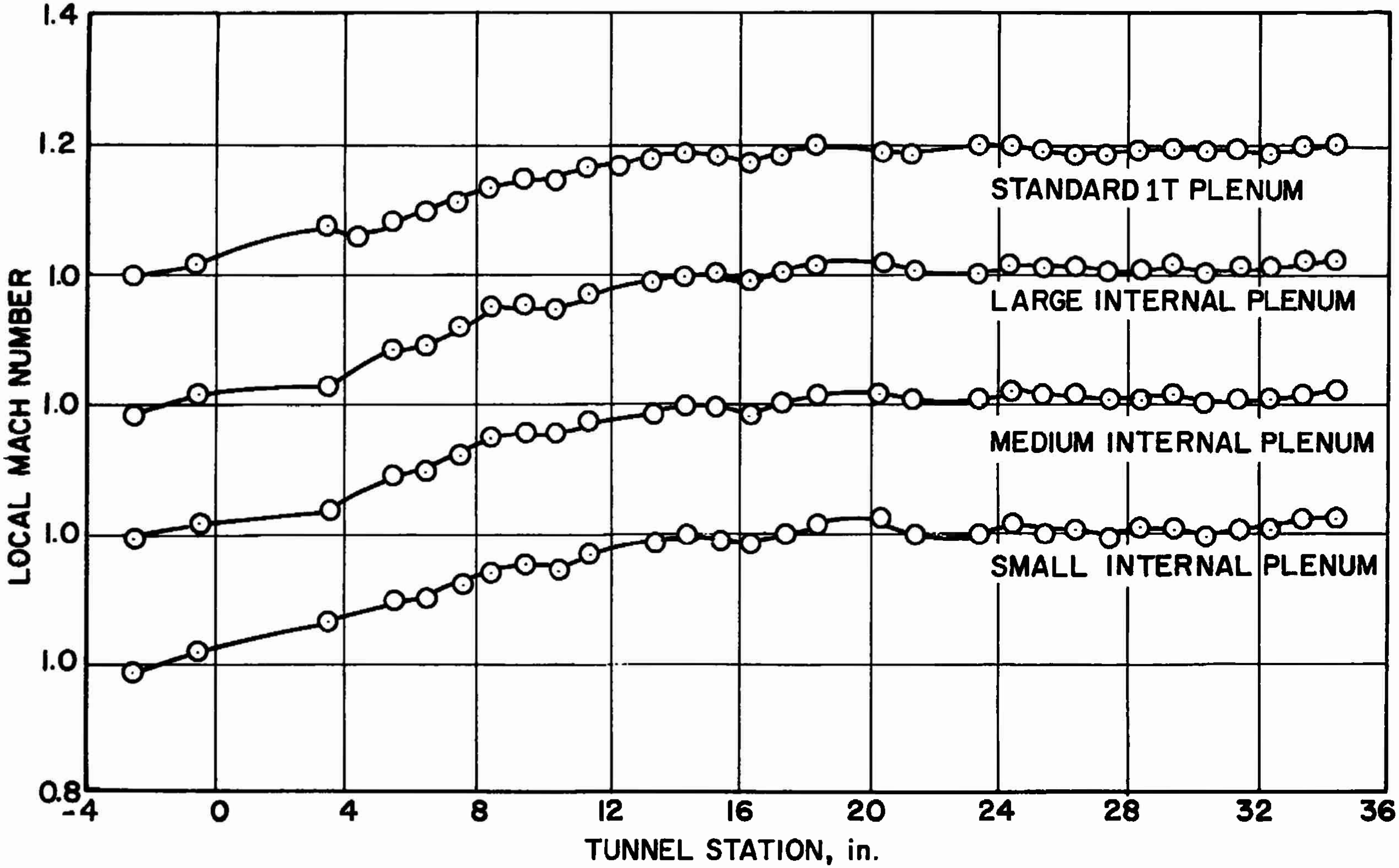
b. $M_\infty = 1.05$
Fig. 11 Continued



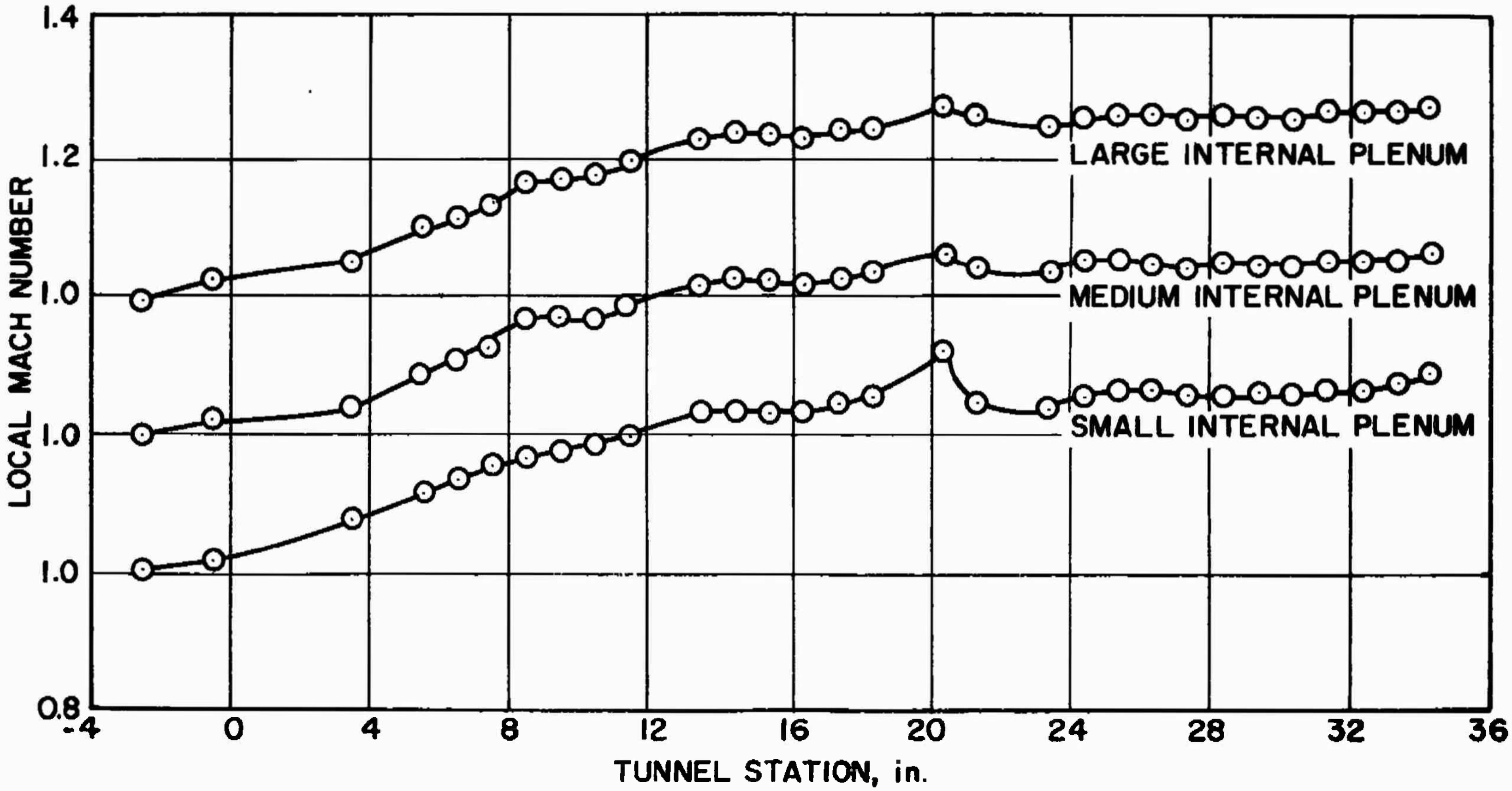
c. $M_\infty = 1.10$
Fig. 11 Continued



d. $M_\infty = 1.15$
Fig. 11 Continued



e. $M_\infty = 1.20$
Fig. 11 Continued



f. $M_\infty = 1.25$
Fig. 11 Concluded

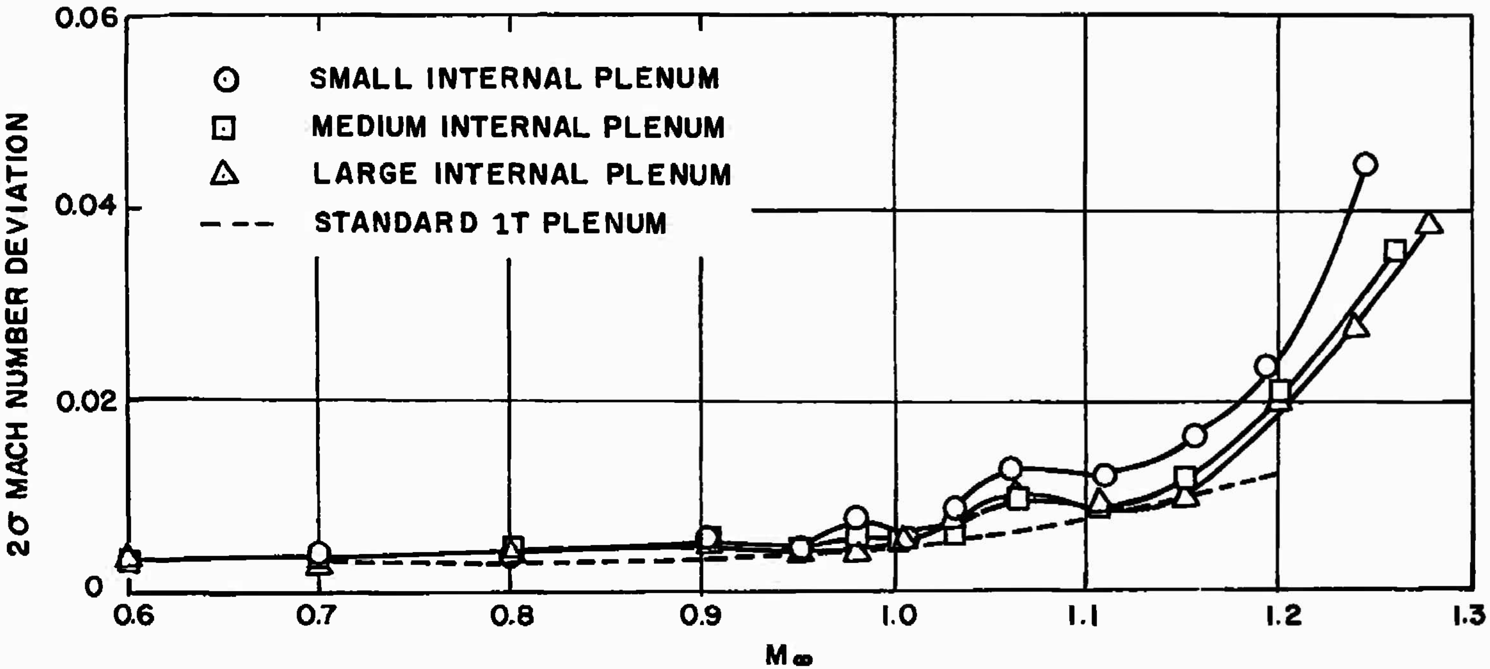
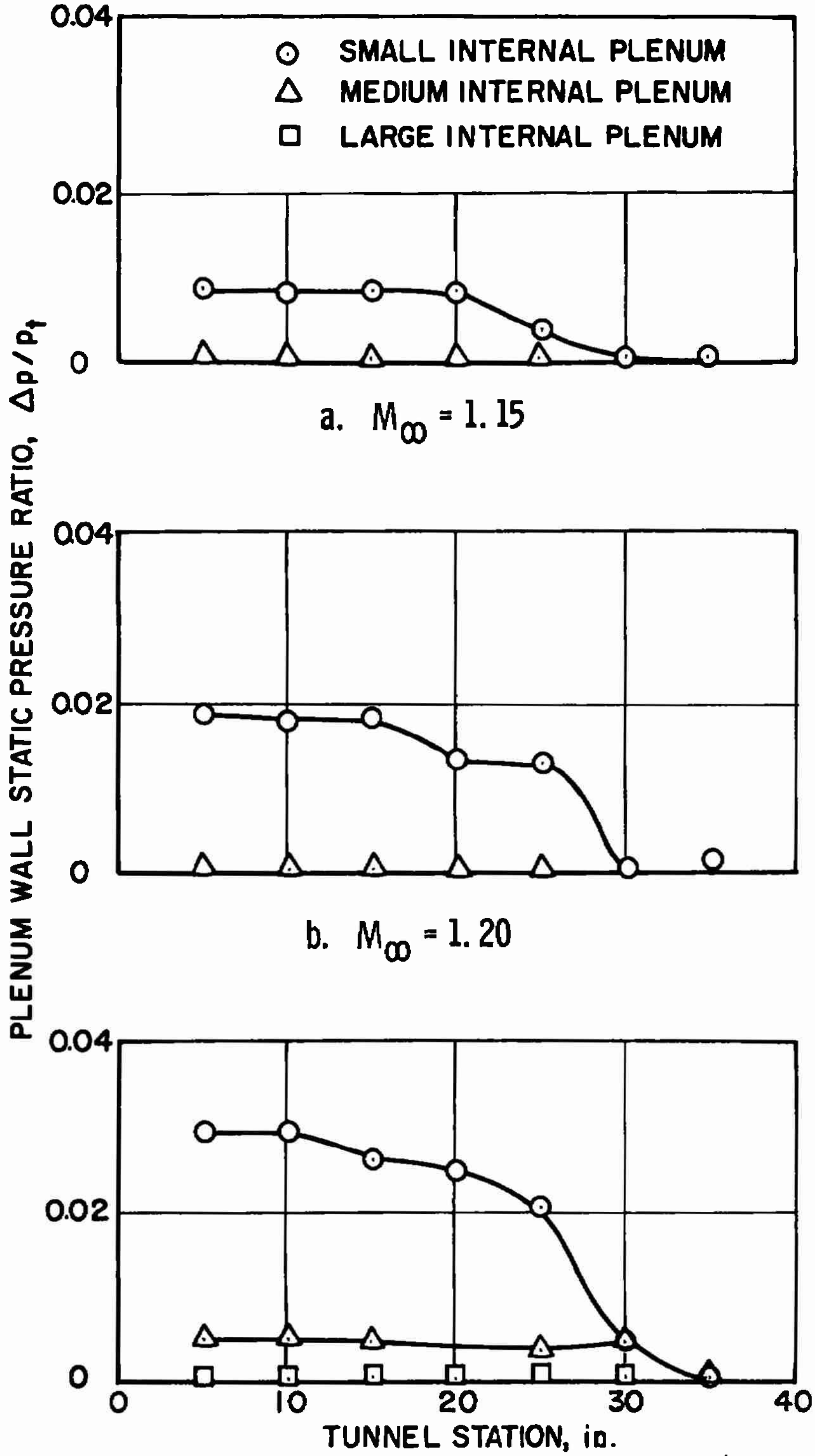


Fig. 12 Centerline Local Mach Number Deviations



c. M_∞ = 1.25

Fig. 13 Plenum Bottom Wall Static Pressure Distribution

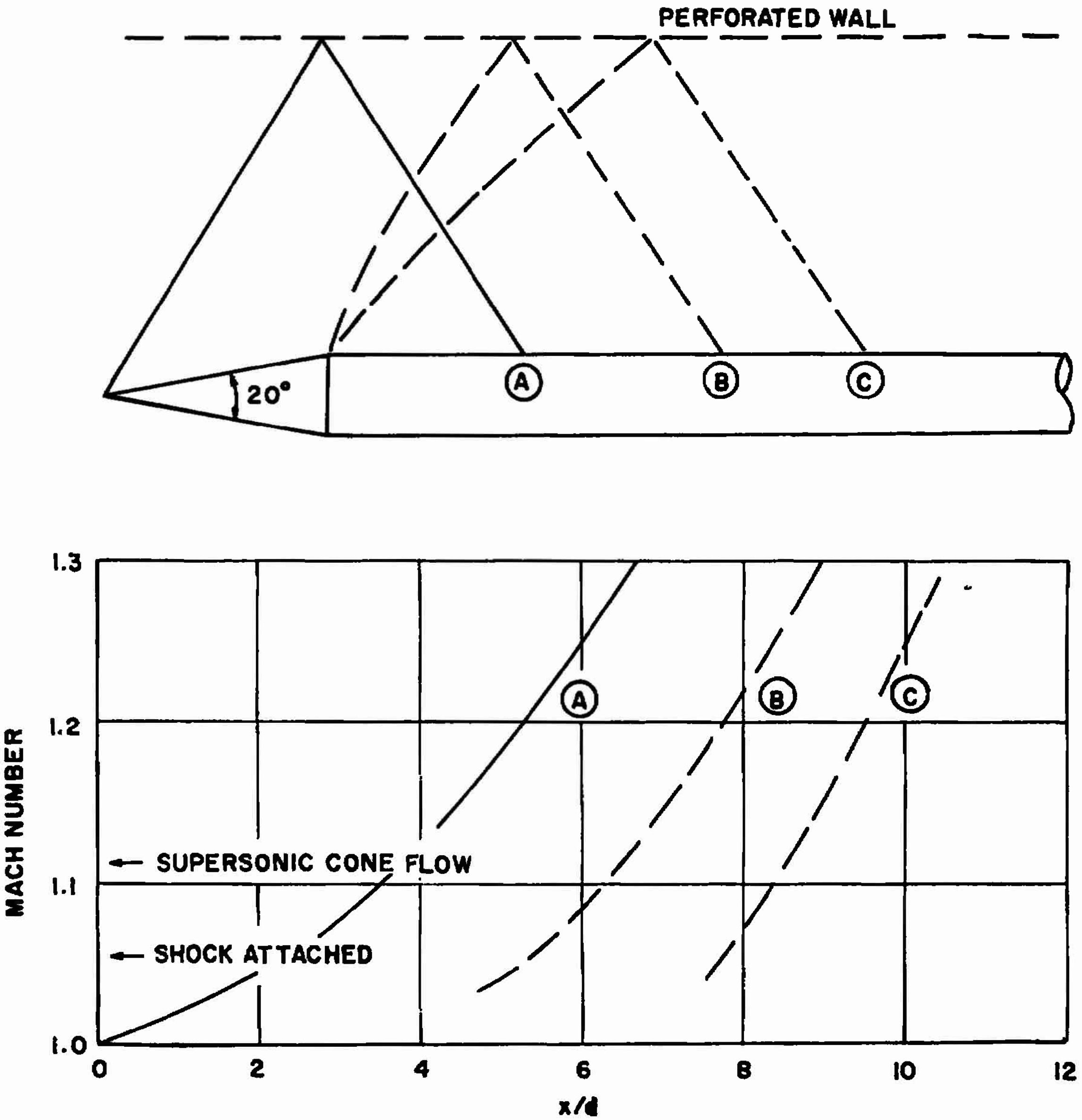
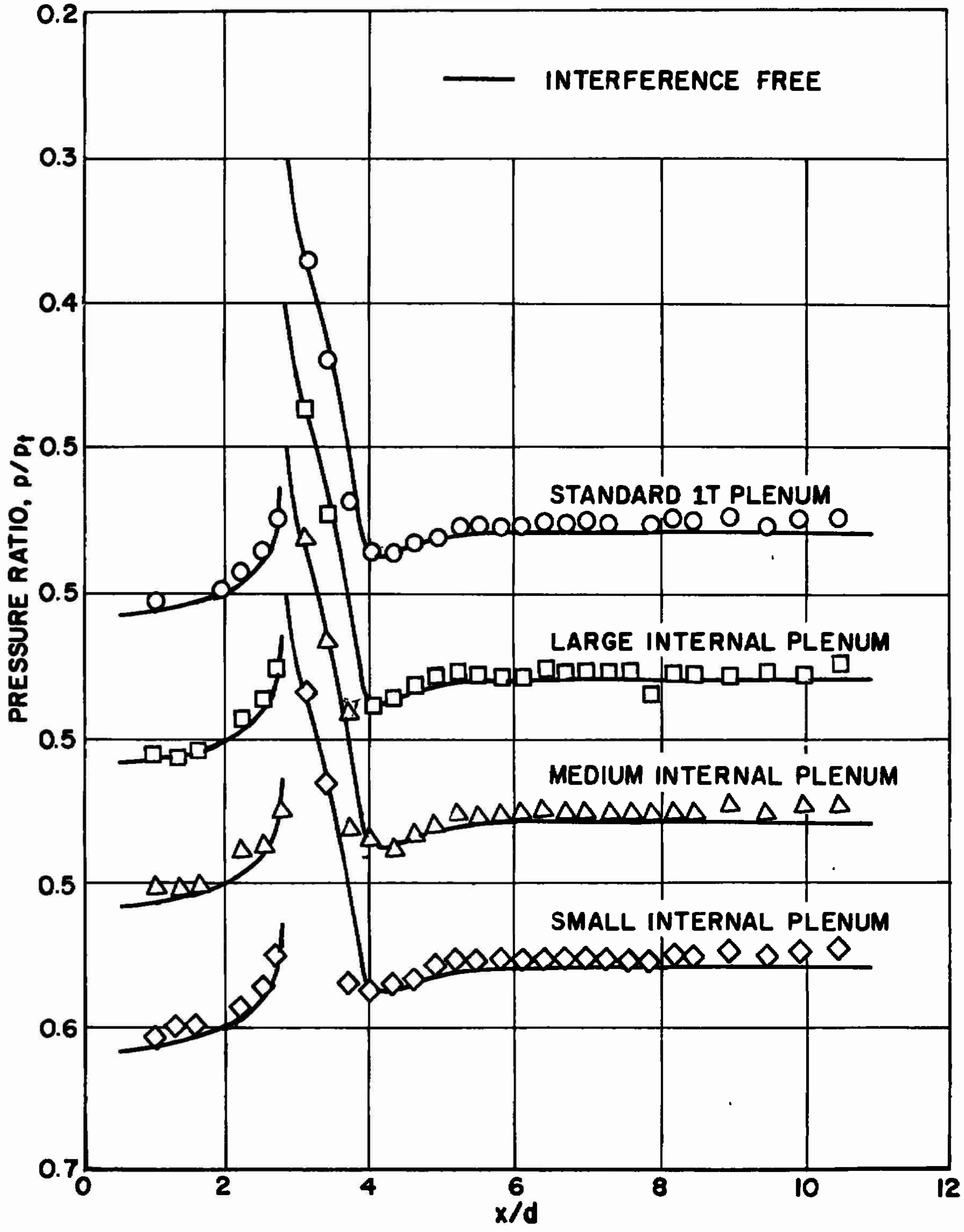
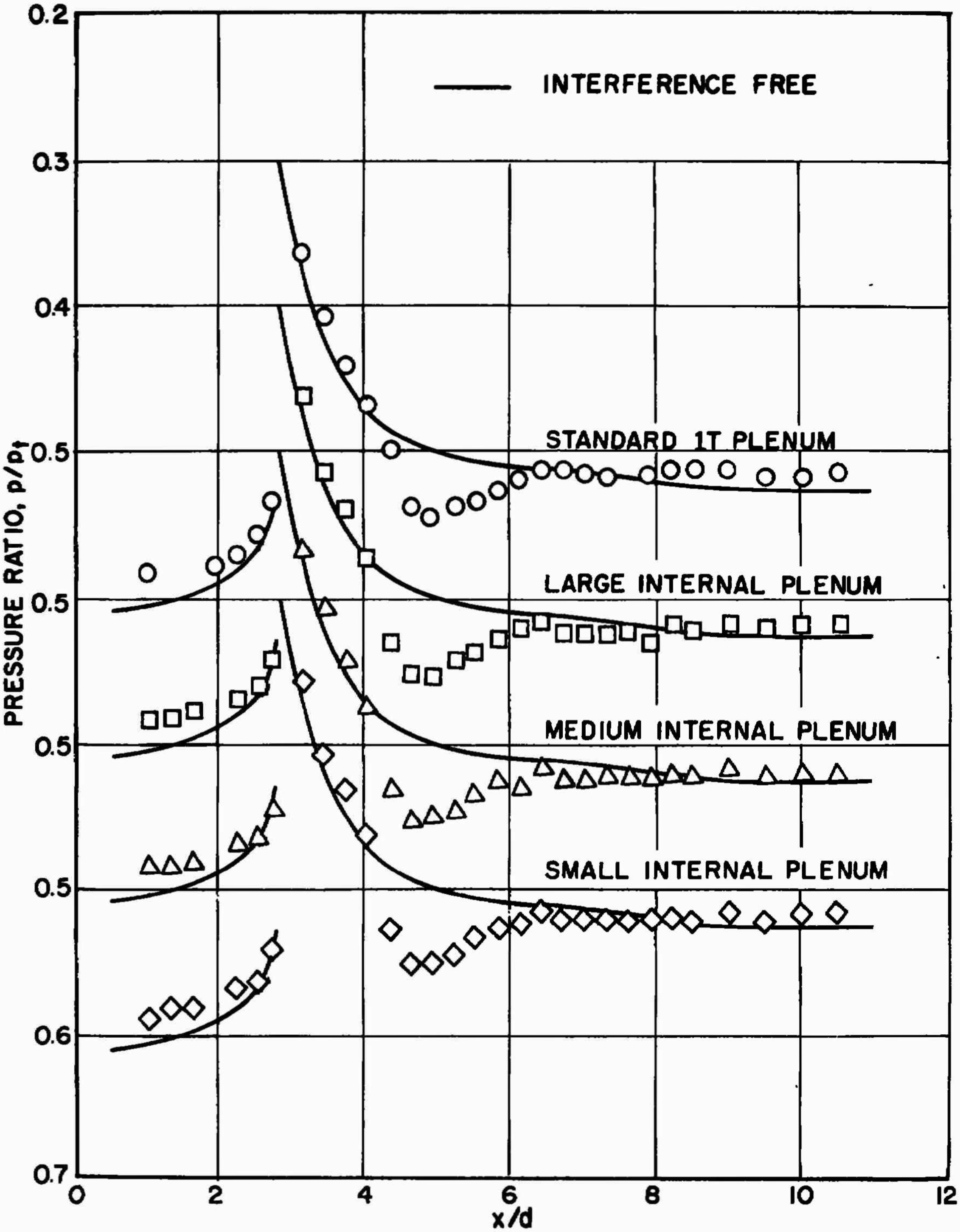


Fig. 14 Approximate Locations of Reflected Wave Disturbances on a 1-percent Blockage, 20-deg, Cone-Cylinder Model

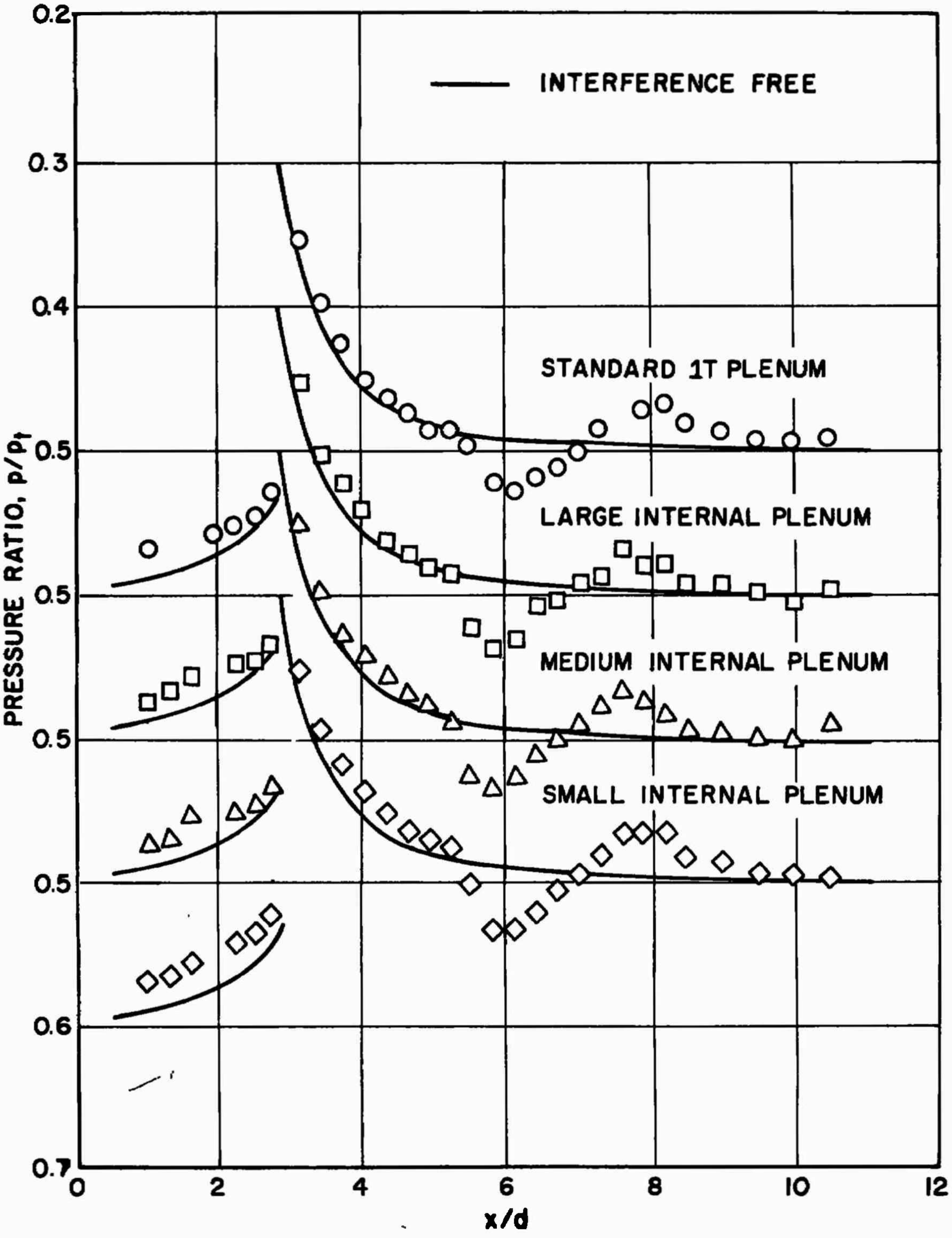


a. $M_\infty = 0.95$

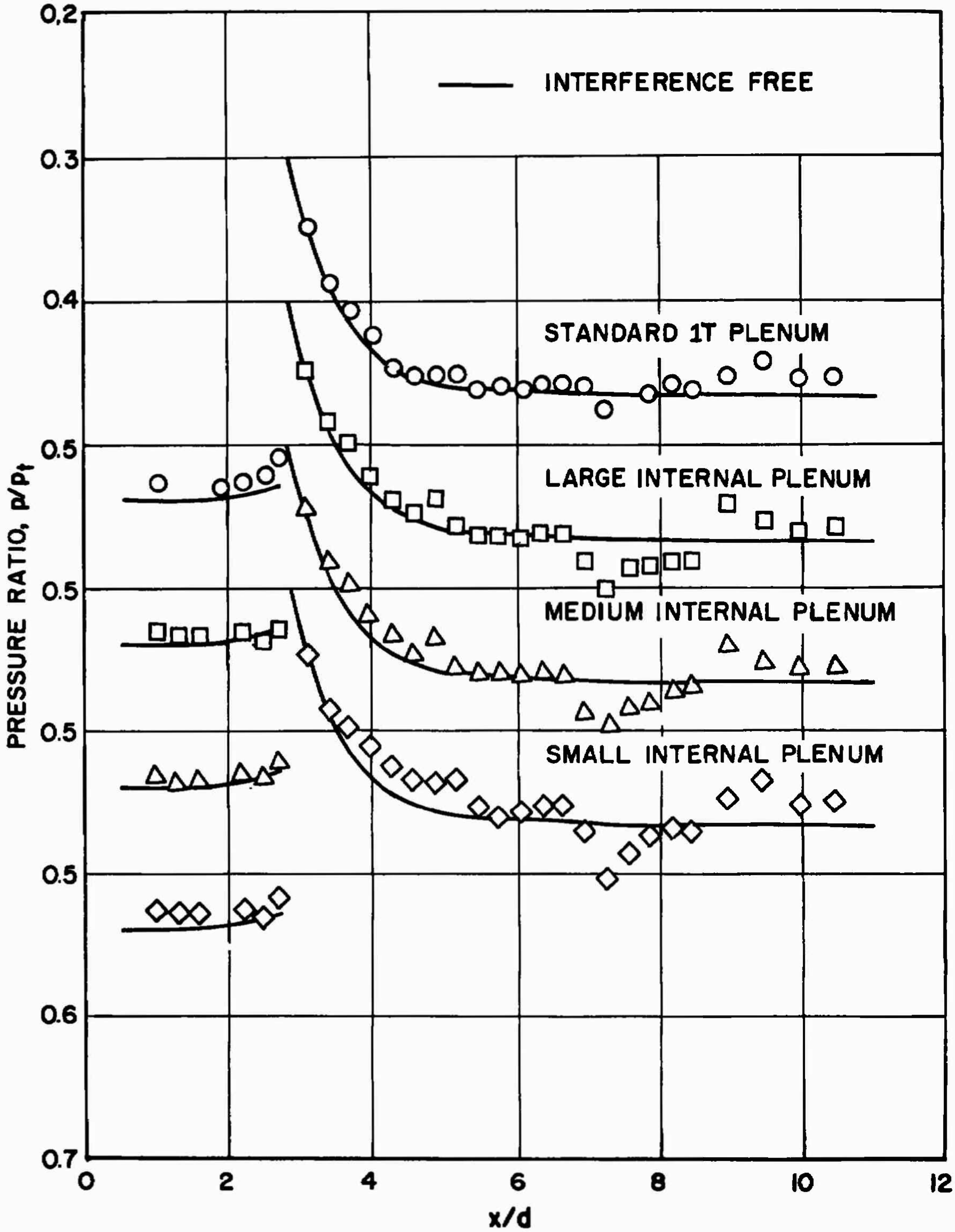
Fig. 15 Cone-Cylinder Pressure Distributions



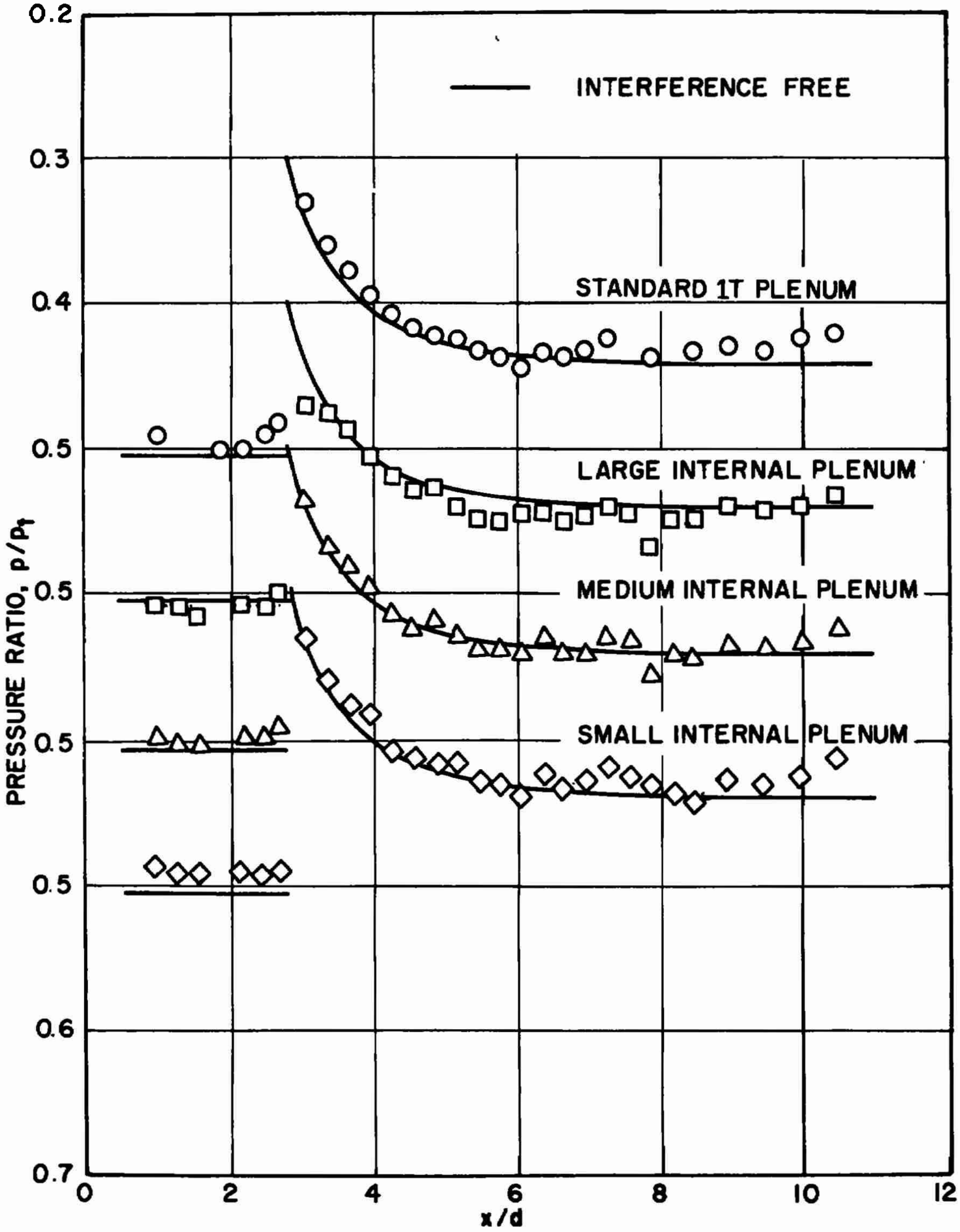
b. $M_\infty = 1.00$
Fig. 15 Continued



c. $M_\infty = 1.05$
Fig. 15 Continued

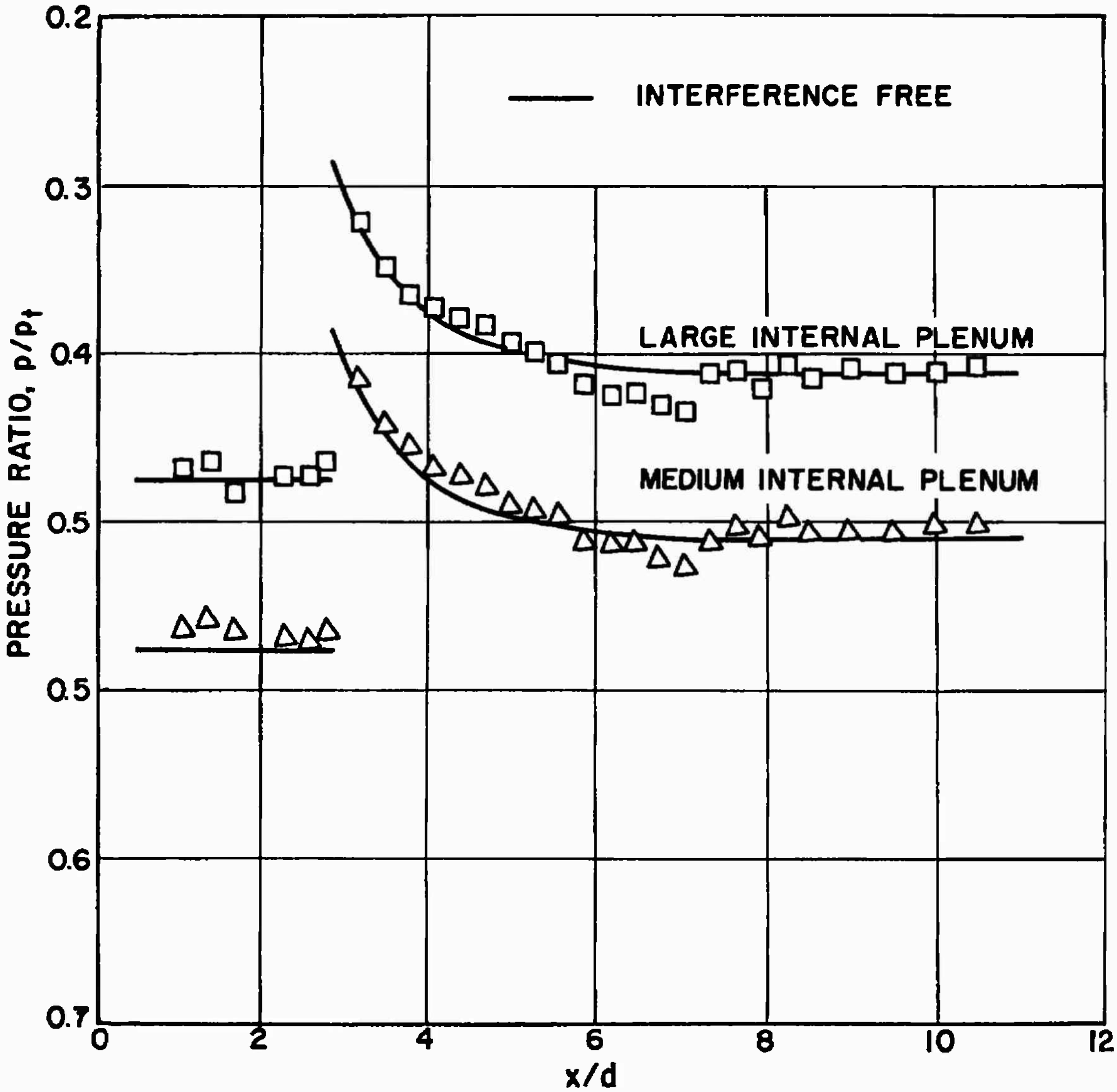


d. $M_\infty = 1.10$
Fig. 15 Continued

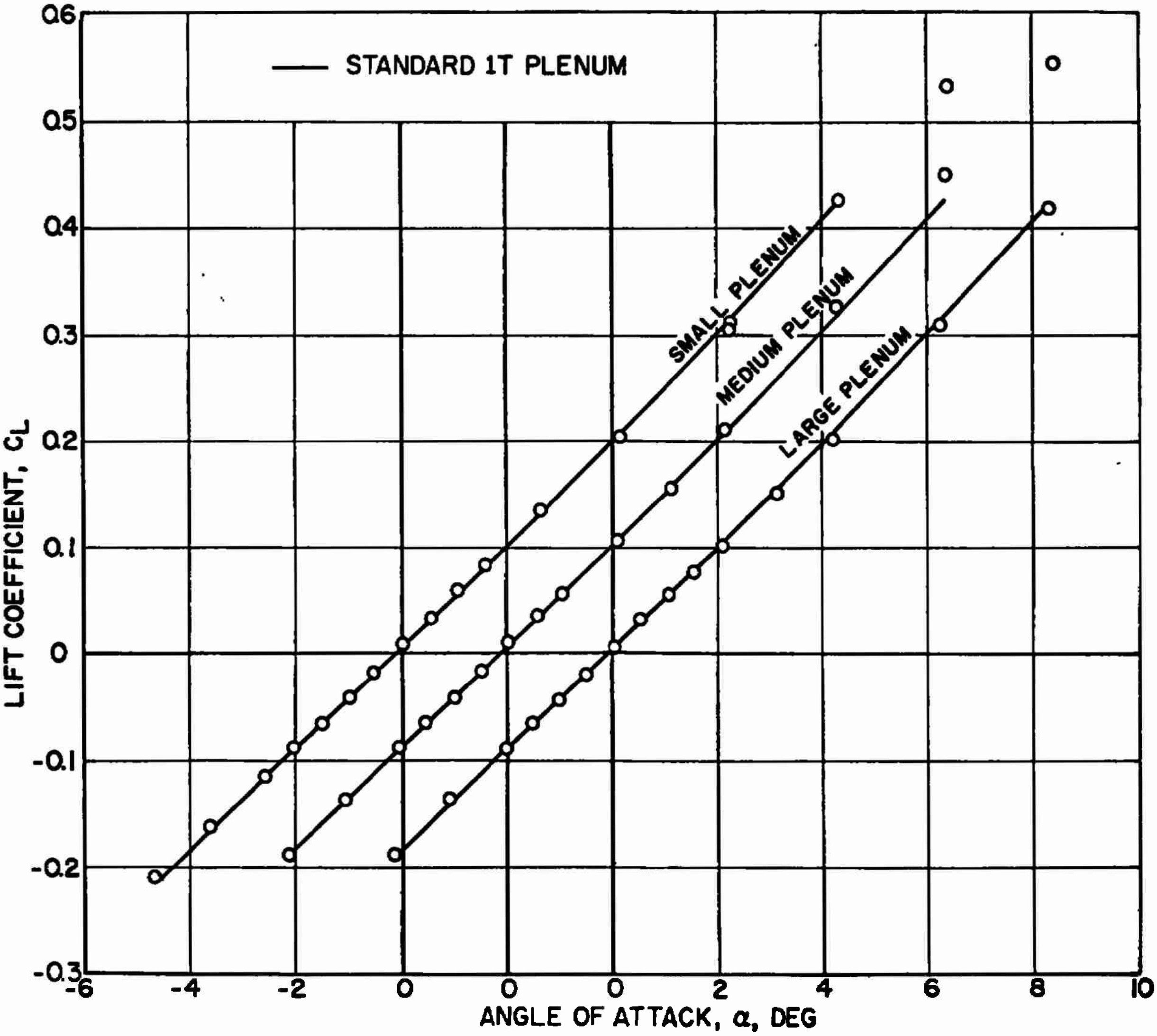


e. $M_\infty = 1.15$

Fig. 15 Continued

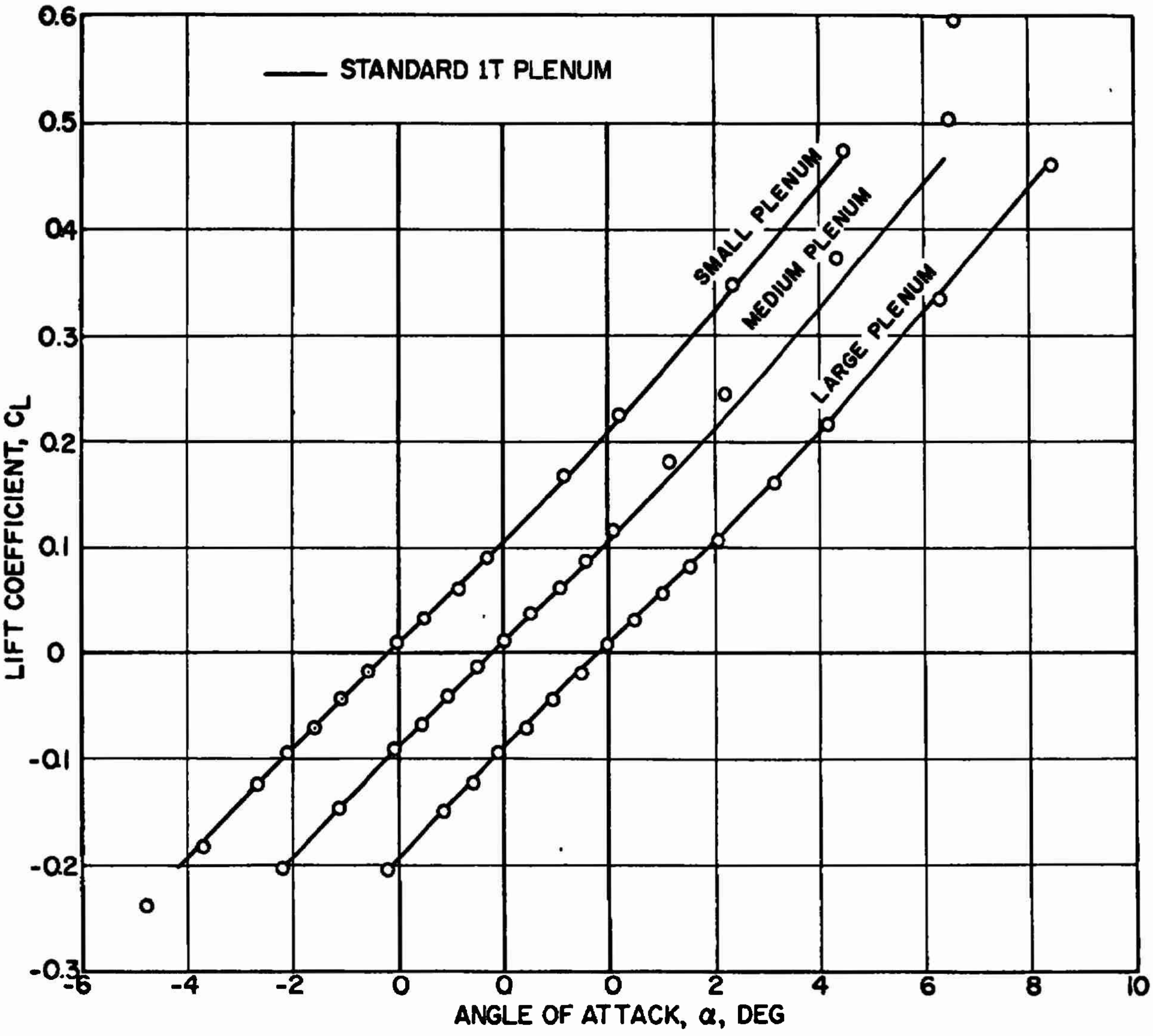


f. $M_\infty = 1.20$
Fig. 15 Concluded

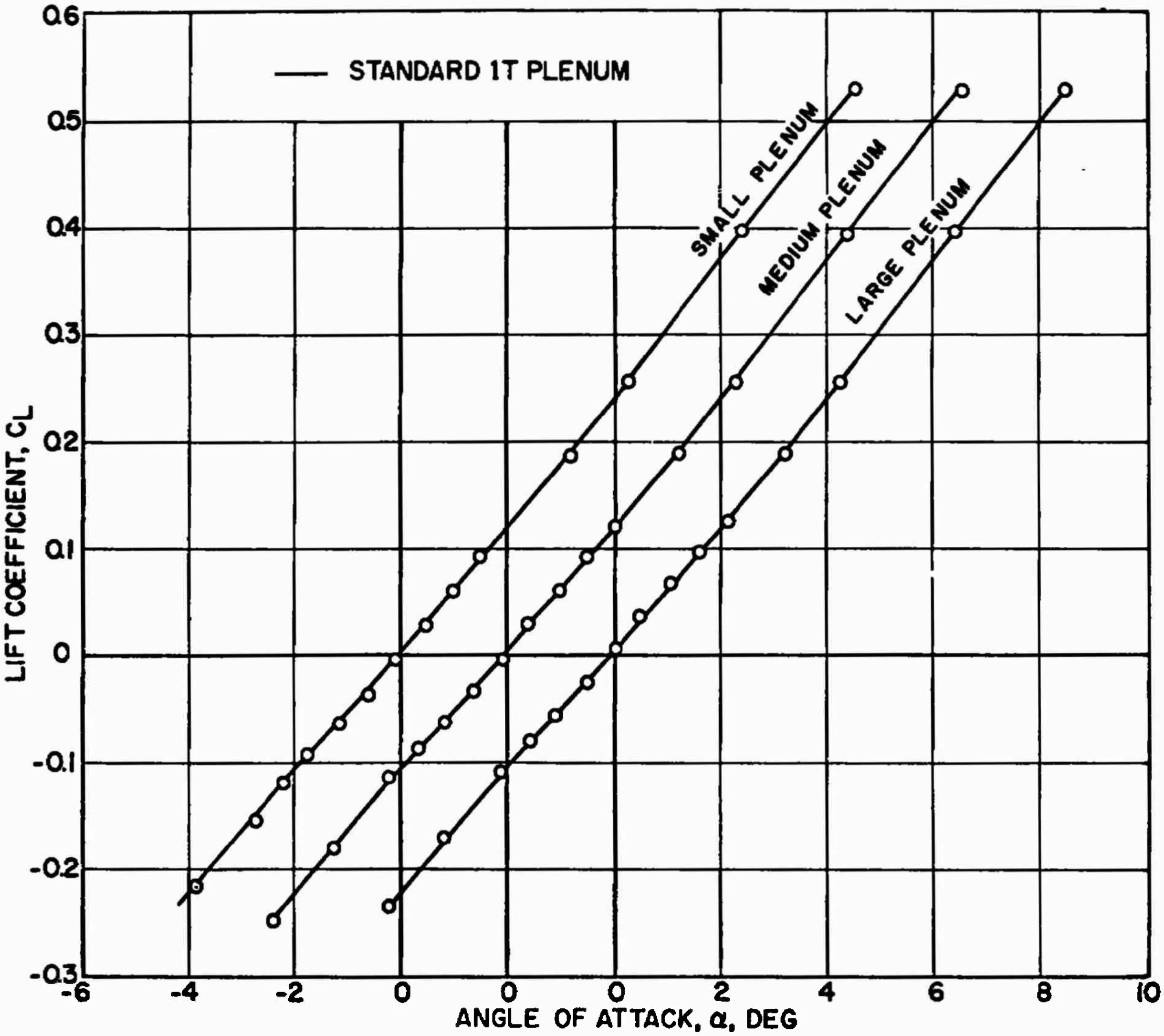


a. $M_\infty = 0.60$

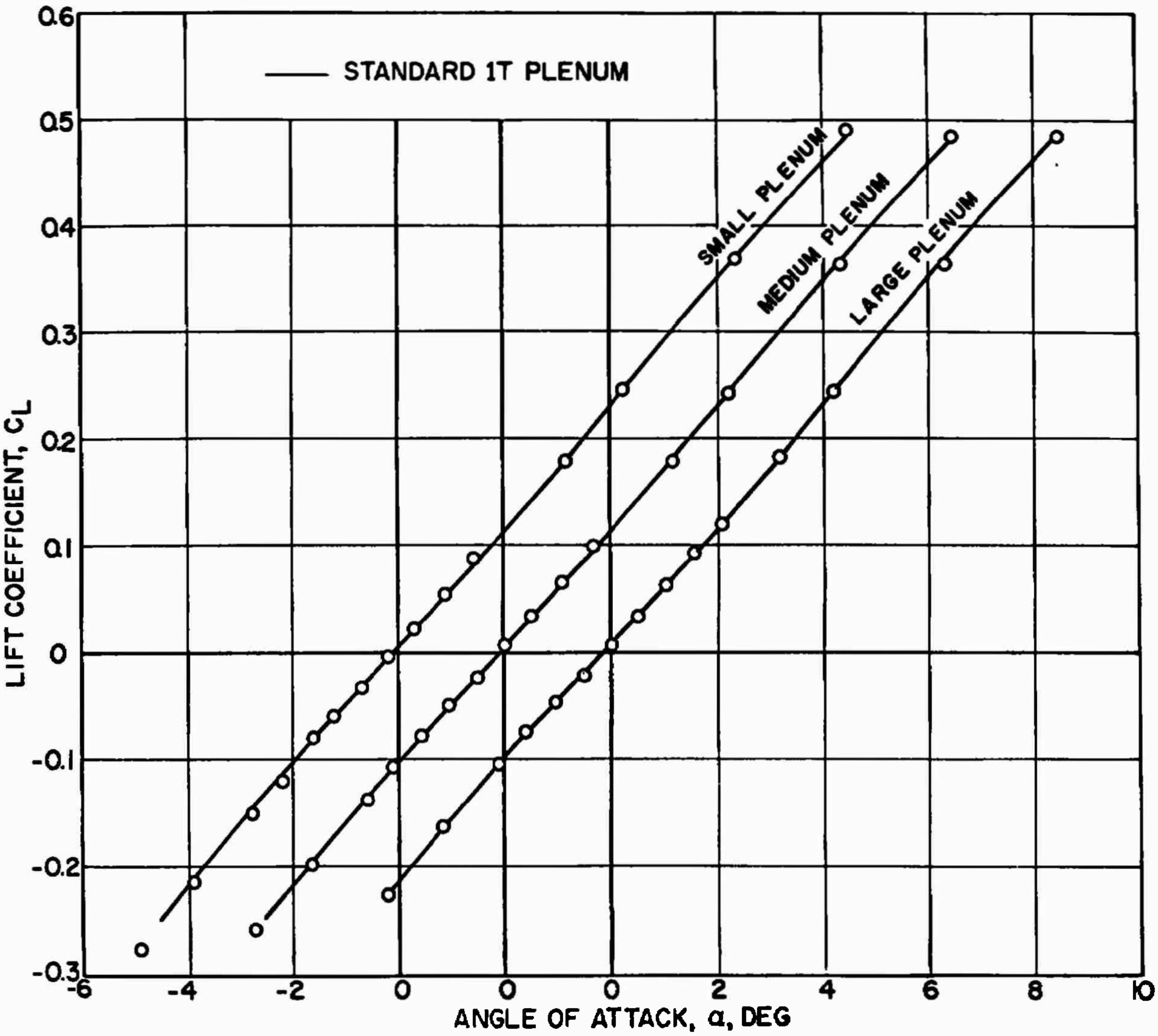
Fig. 16 Variation of Lift Coeffficient with Angle of Attack



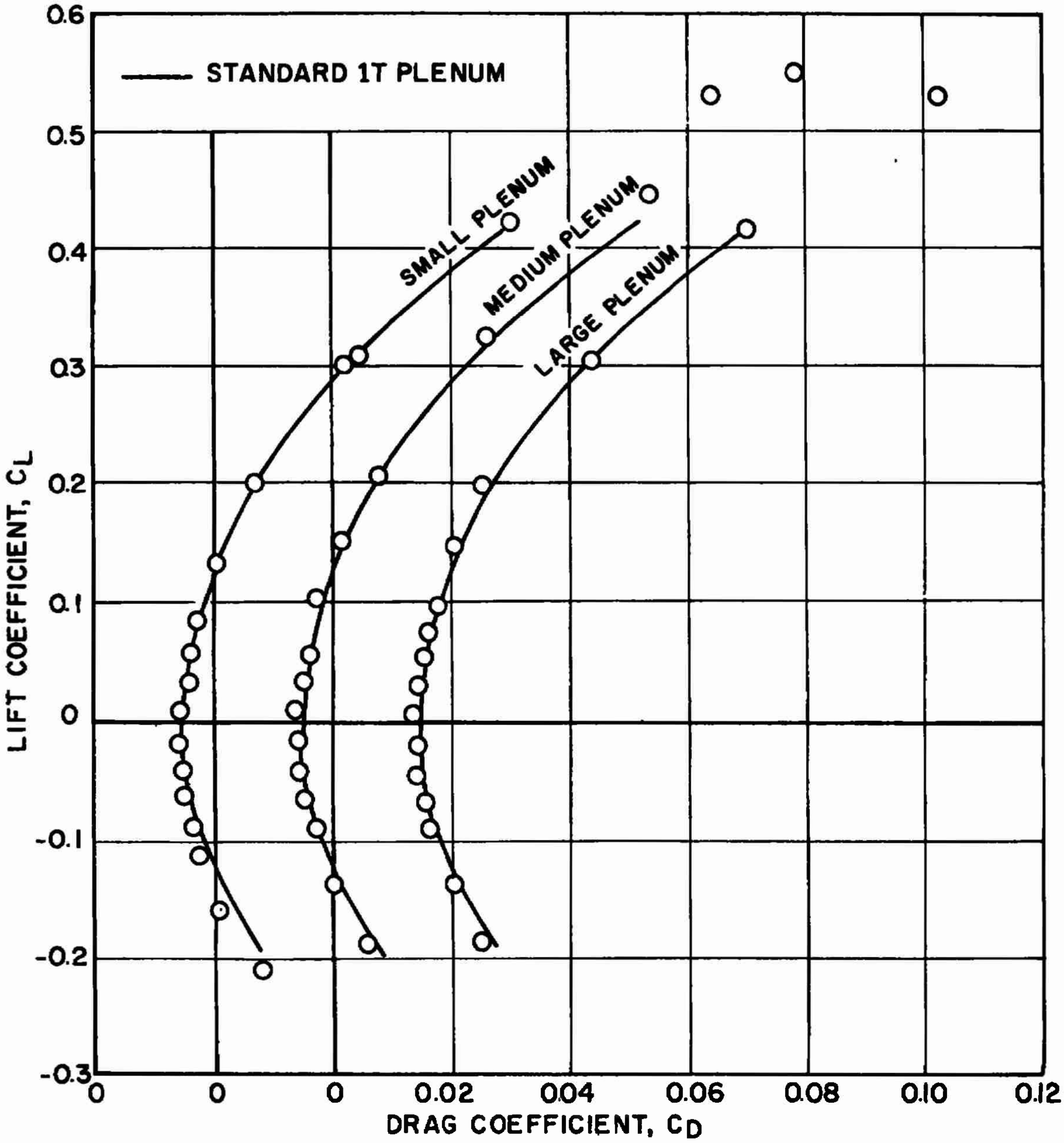
b. $M_\infty = 0.80$
Fig. 16 Continued



c. M_∞ = 1.00
Fig. 16 Continued

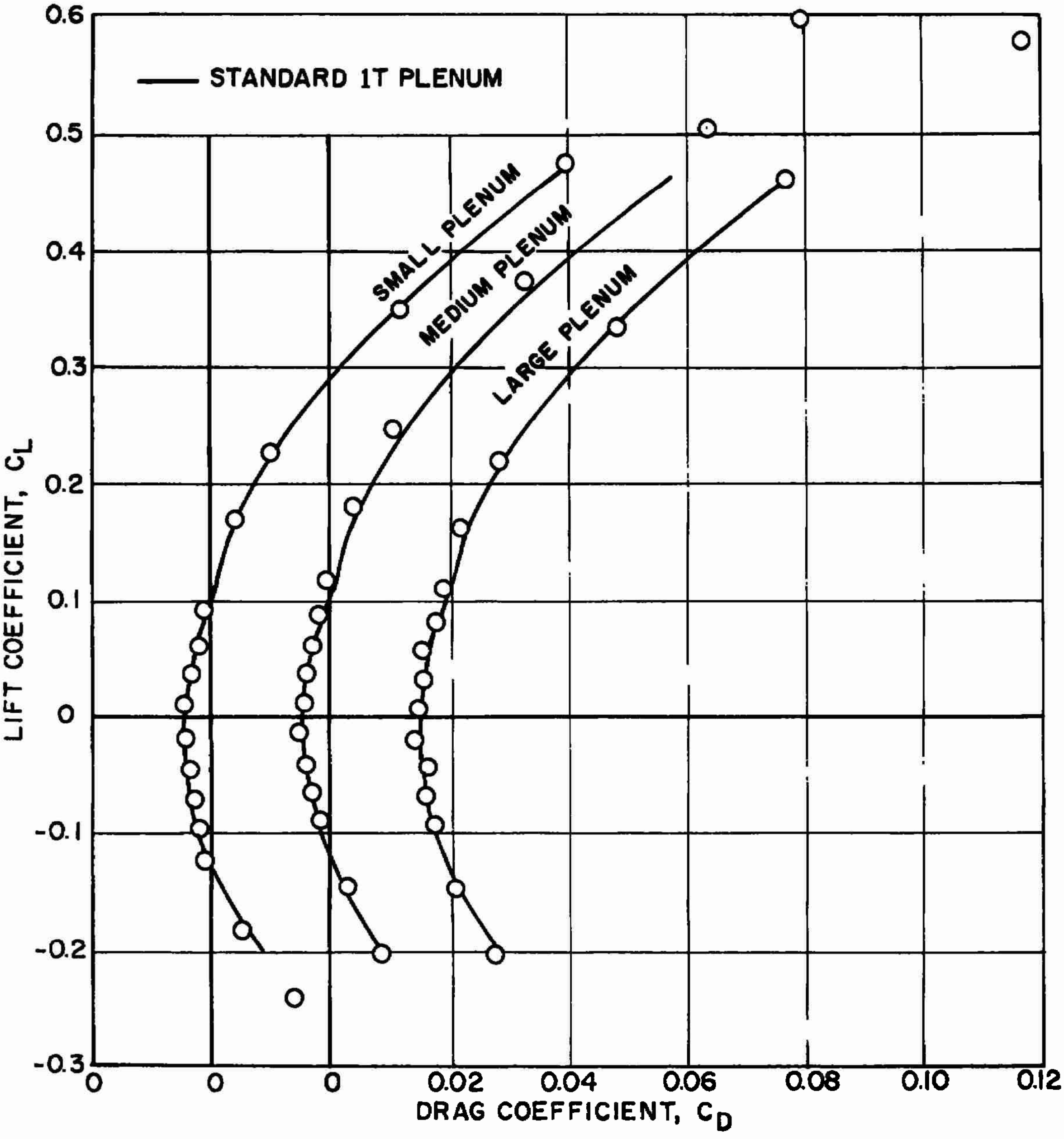


d. $M_\infty = 1.20$
Fig. 16 Concluded

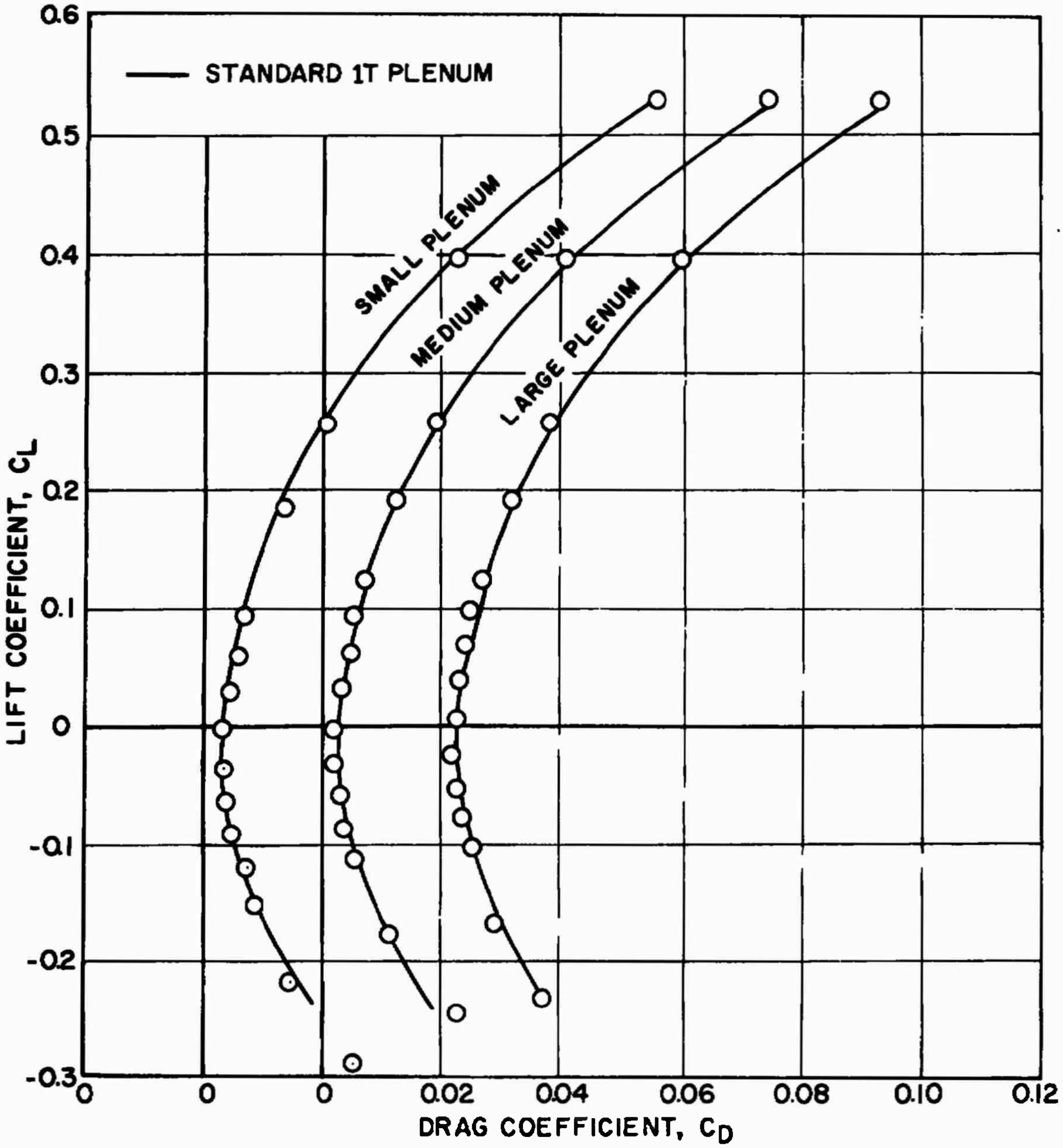


a. $M_\infty = 0.60$

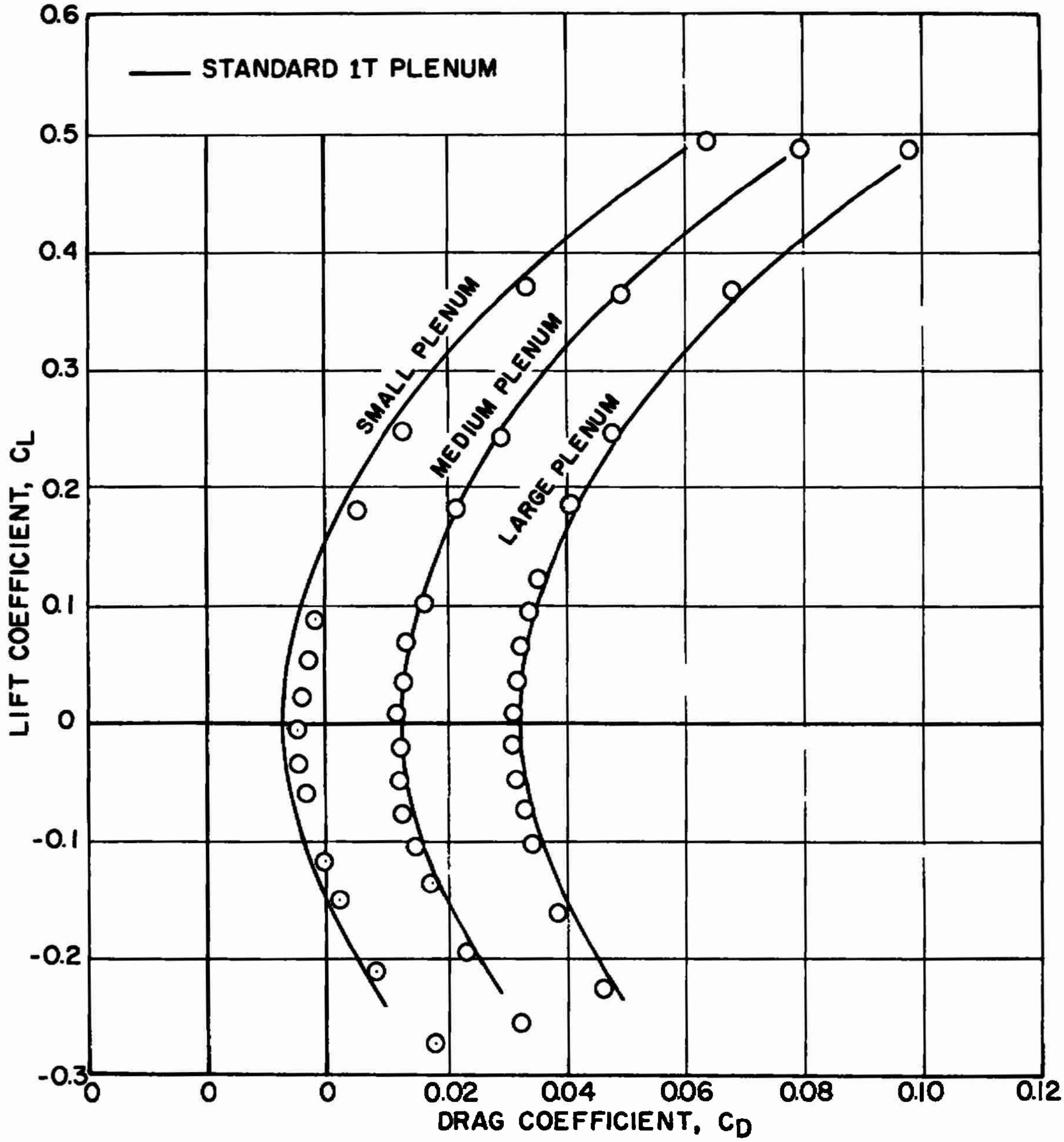
Fig. 17 Variation of Lift Coefficient with Forebody Drag Coefficient



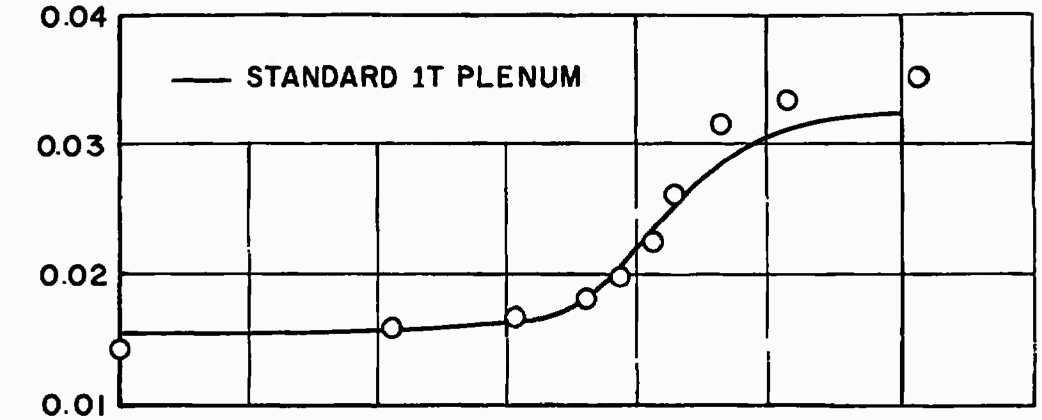
b. $M_\infty = 0.80$
Fig. 17 Continued



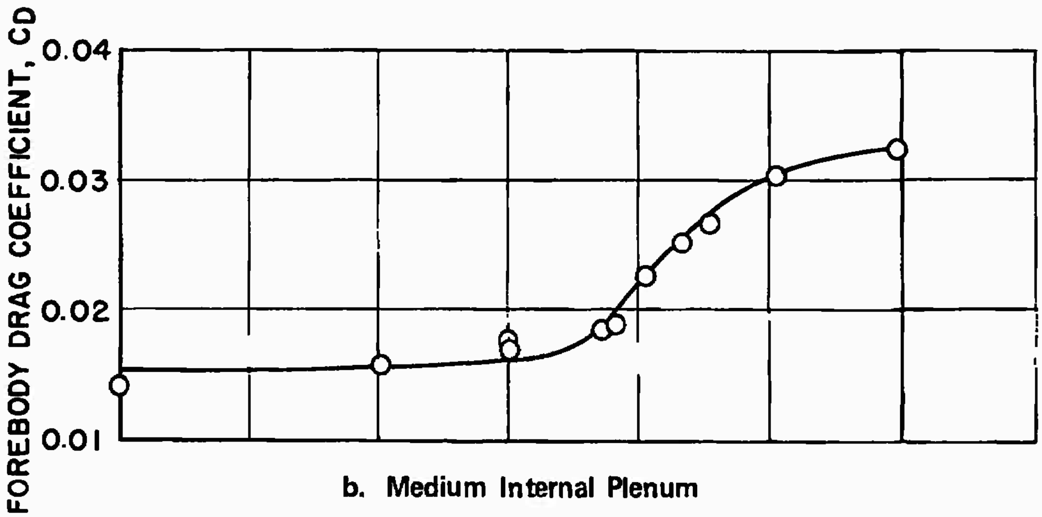
c. $M_\infty = 1.00$
Fig. 17 Continued



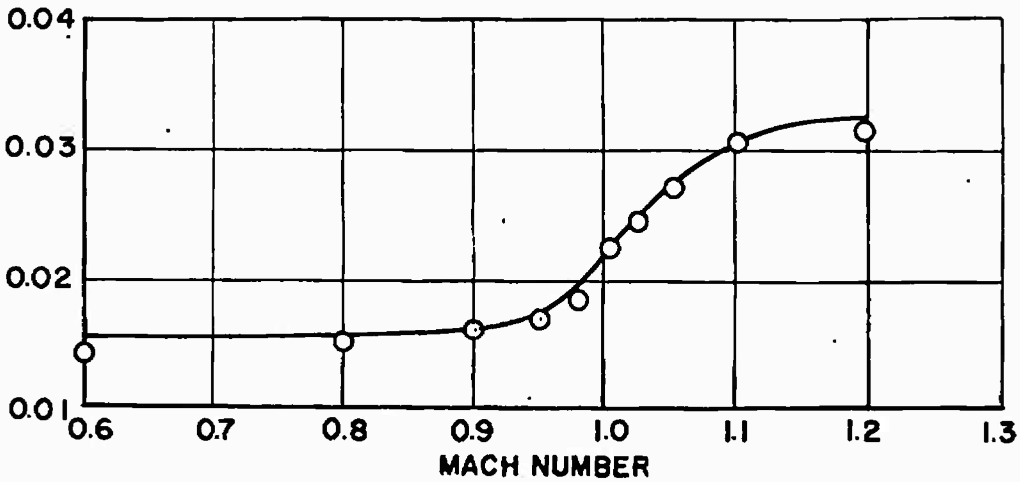
d. $M_\infty = 1.20$
Fig. 17 Concluded



a. Small Internal Plenum

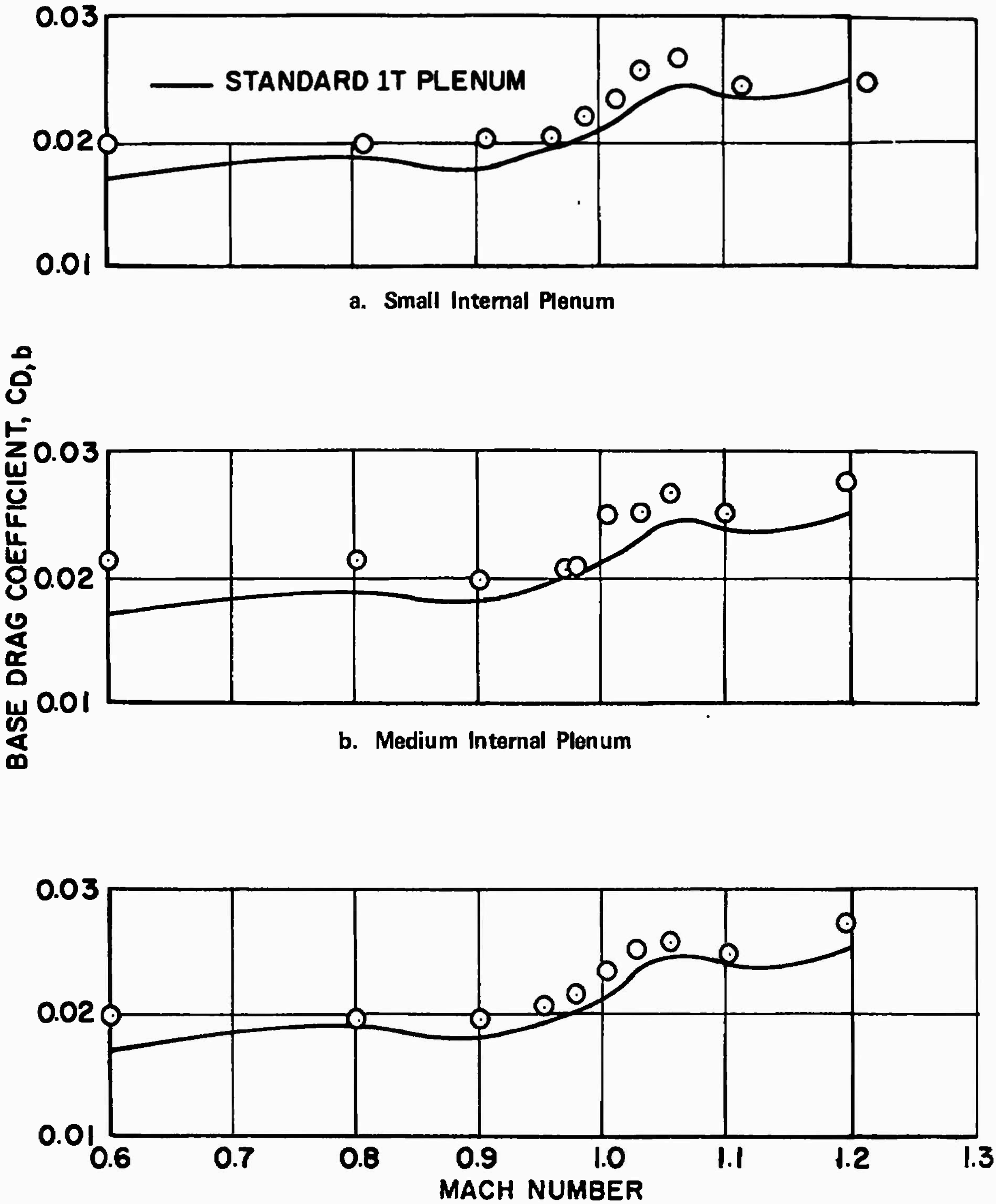


b. Medium Internal Plenum



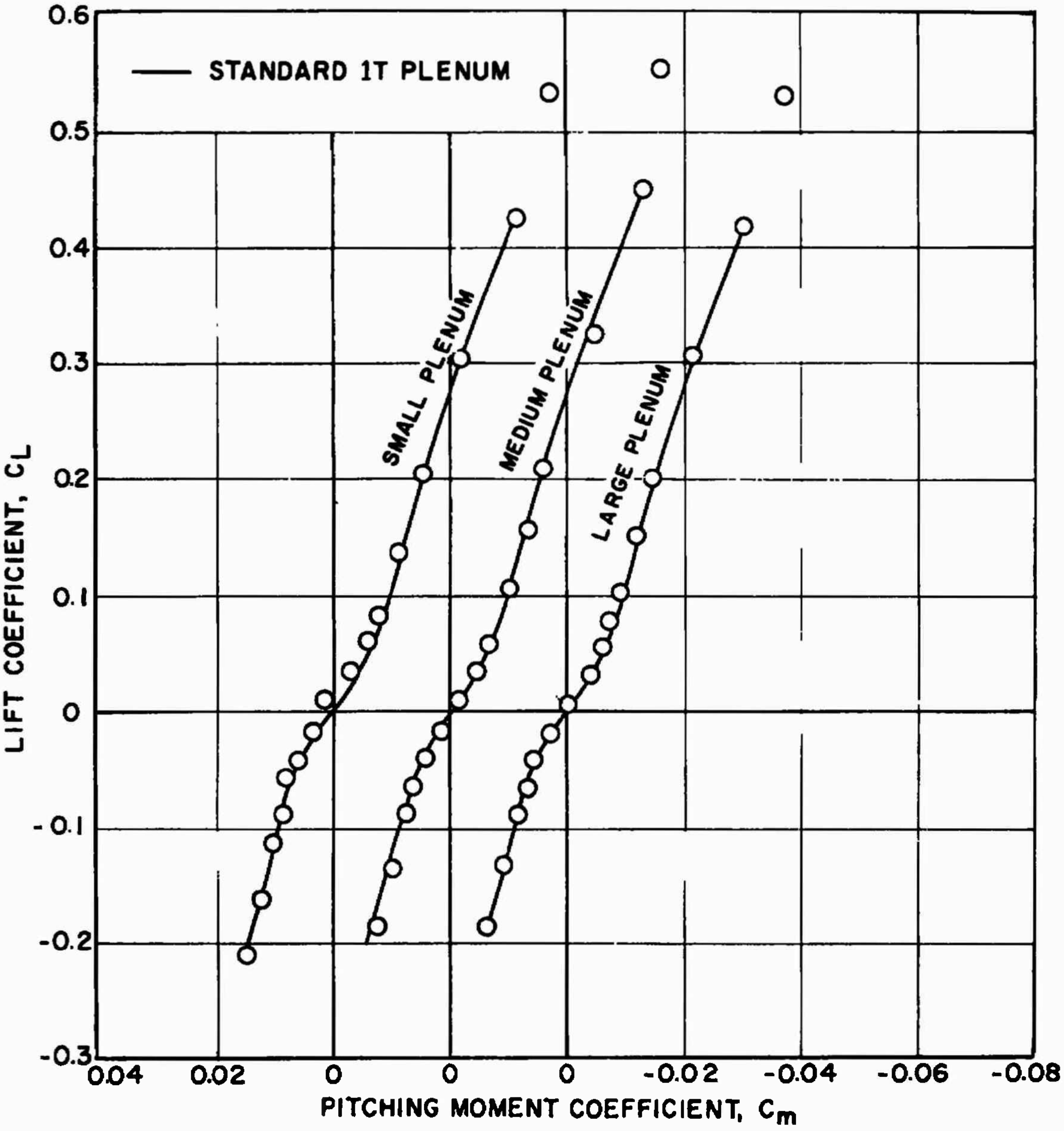
c. Large Internal Plenum

Fig. 18 Variation of Forebody Drag Coefficient at Zero Lift Coefficient with Mach Number



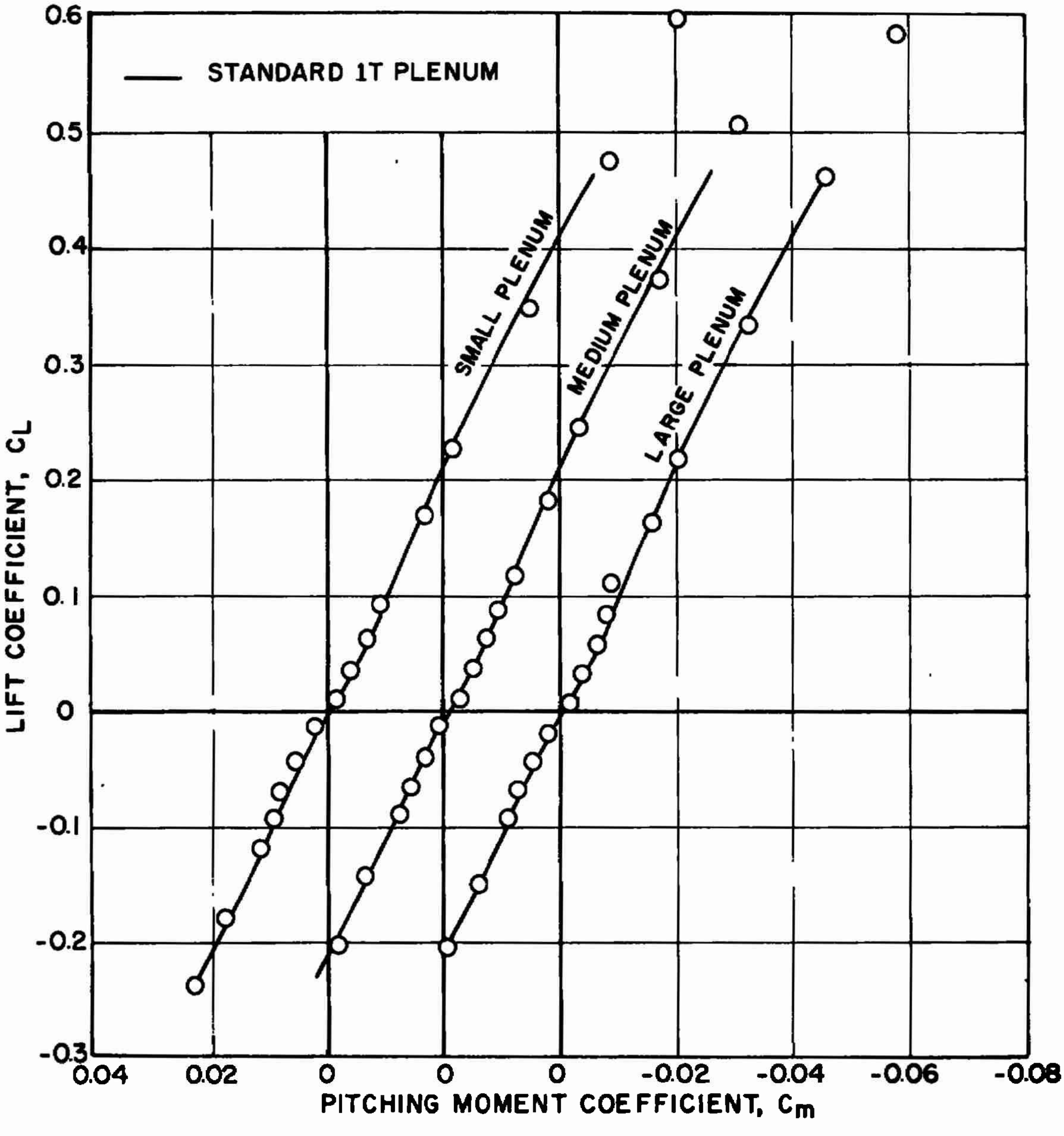
c. Large Internal Plenum

Fig. 19 Variation of Base Drag Coefficient at Zero Lift Coefficient with Mach Number

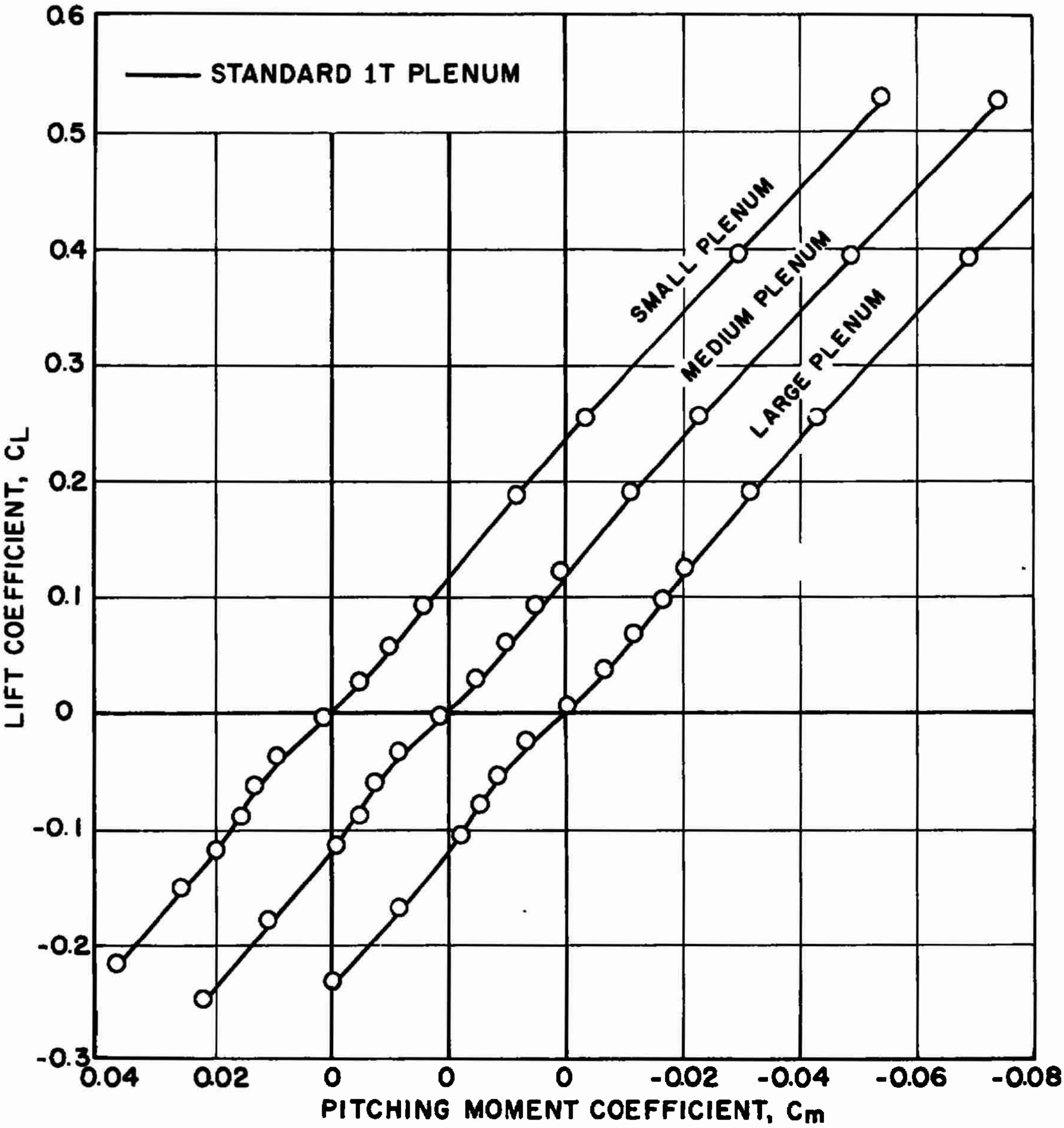


a. $M_\infty = 0.60$

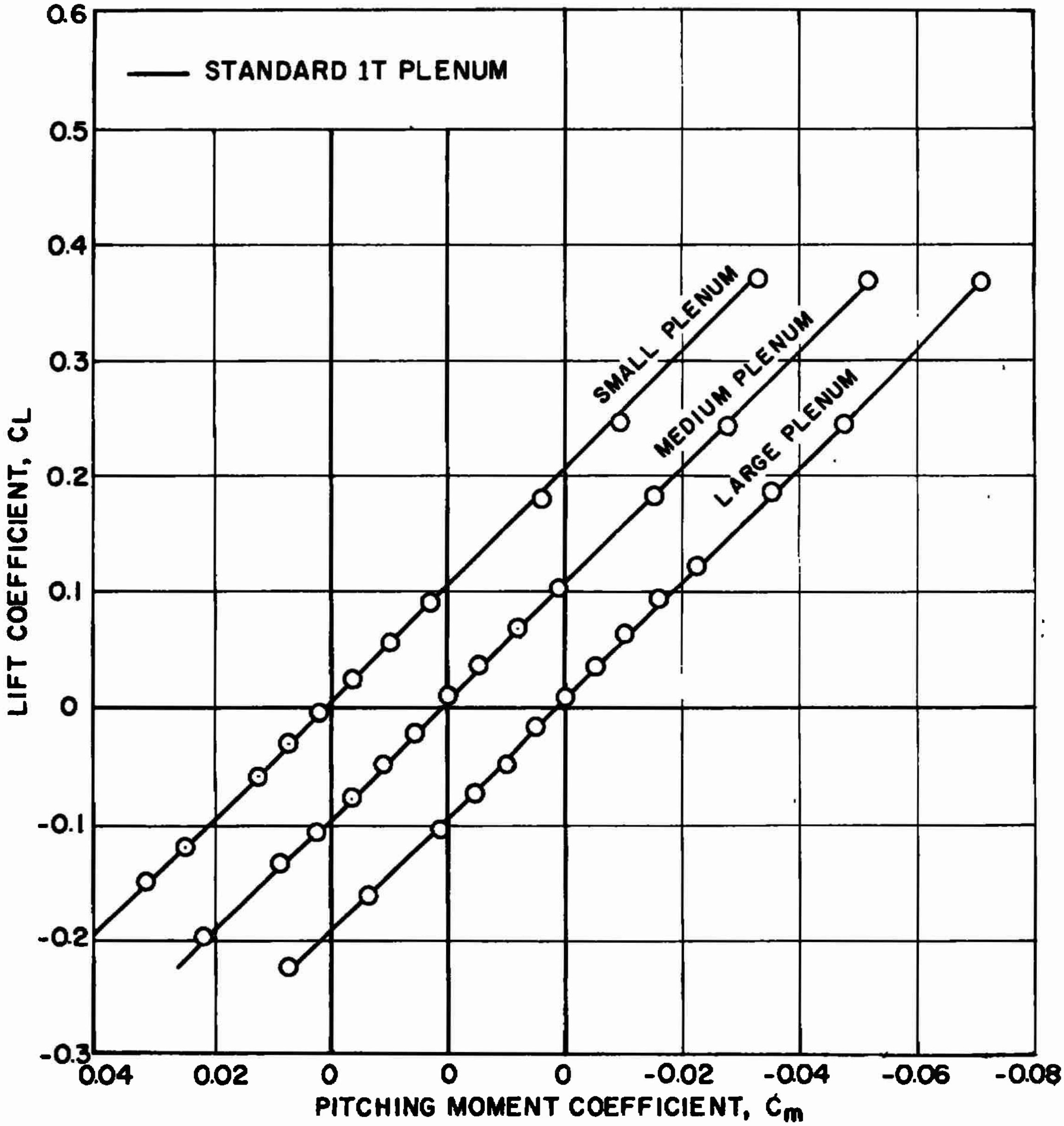
Fig. 20 Variation of Lift Coefficient with Pitching Moment Coefficient



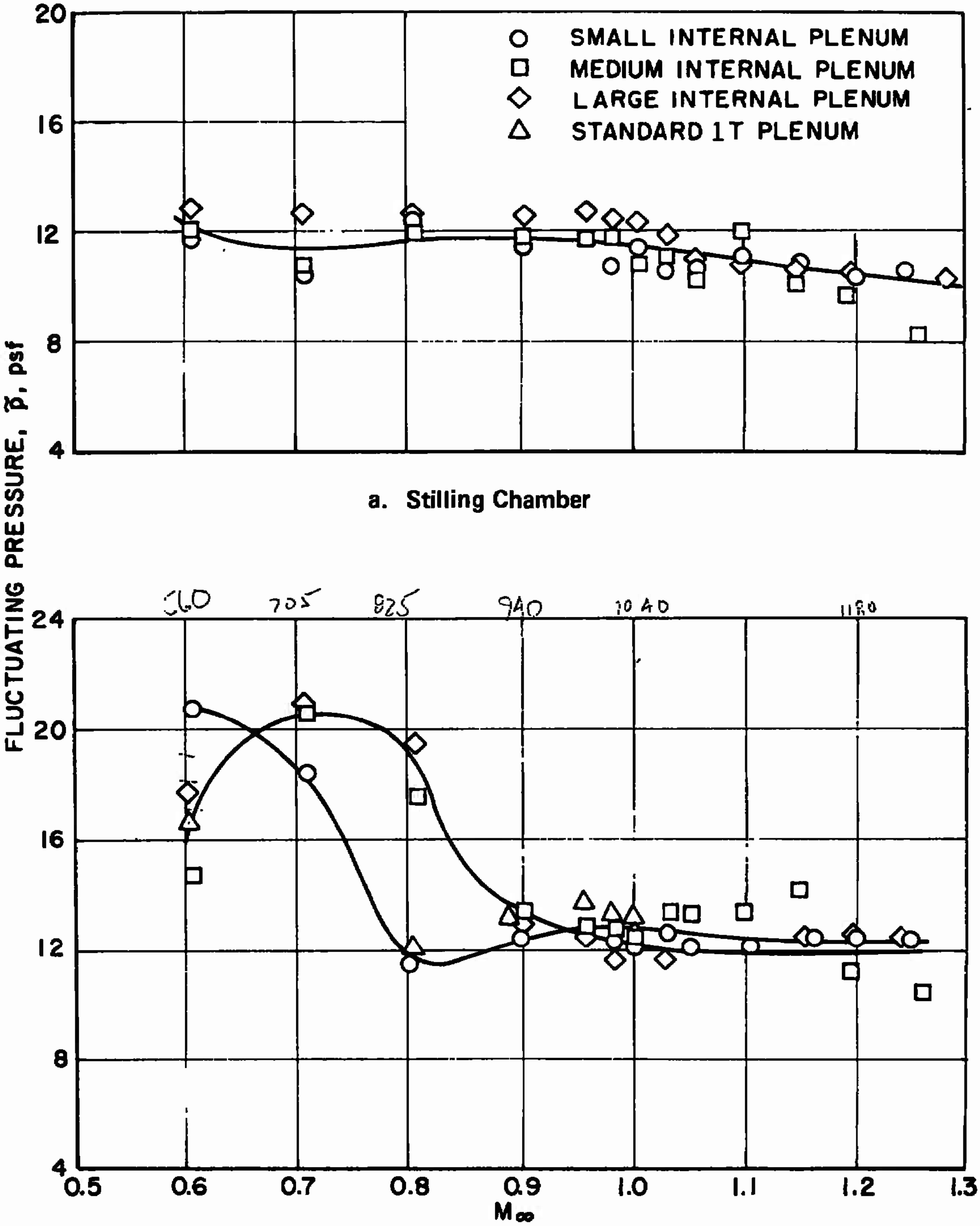
b. $M_\infty = 0.80$
Fig. 20 Continued



c. $M_\infty = 1.00$
Fig. 20 Continued

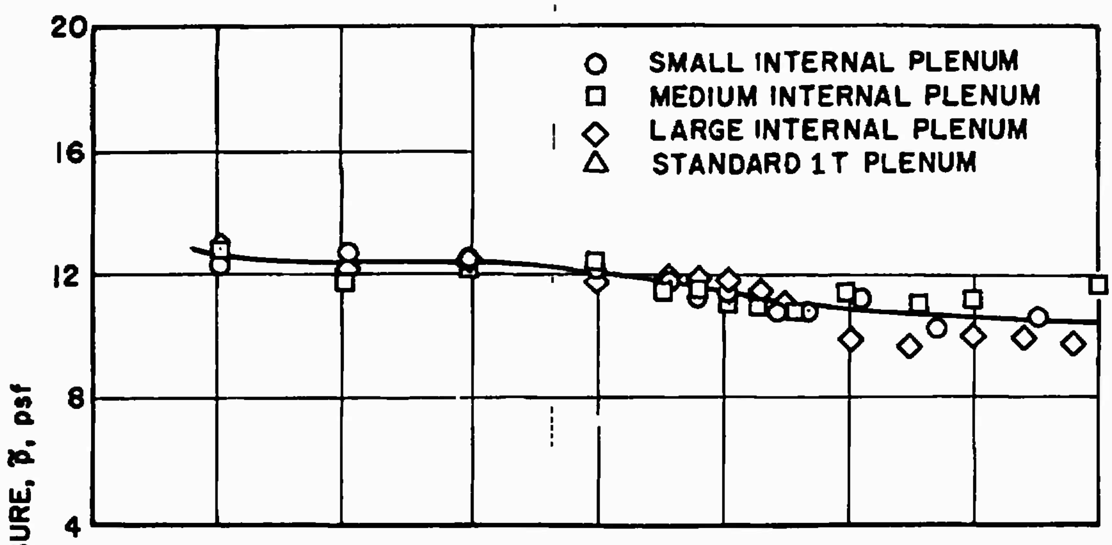


d. $M_\infty = 1.20$
Fig. 20 Concluded

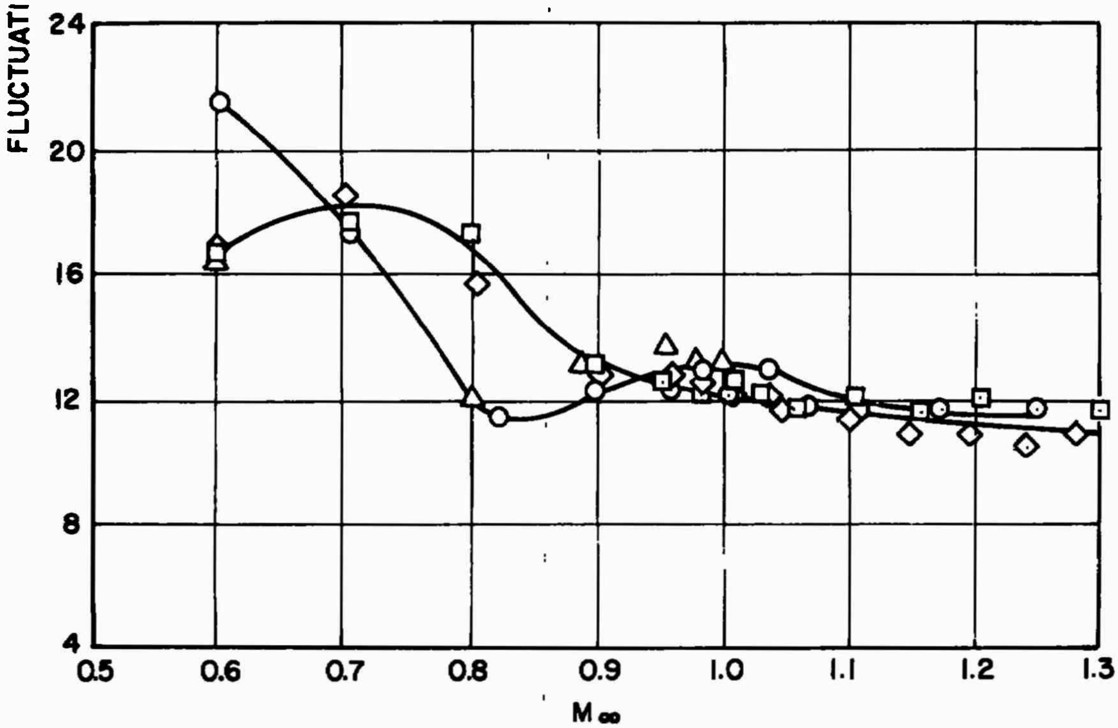


b. Test Section

Fig. 21 Variation of Fluctuating Static Pressure with Mach Number with the Static Probe in the Test Section



a. Stilling Chamber



b. Test Section

Fig. 22 Variation of Fluctuating Static Pressure with Mach Number with the Cone-Cylinder Model in the Test Section

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Arnold Engineering Development Center, ARO, Inc., Operating Contractor, Arnold Air Force Station, Tennessee 37389	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

THE EFFECT OF PLENUM VOLUME ON THE TEST SECTION FLOW CHARACTERISTICS OF A PERFORATED WALL TRANSONIC WIND TUNNEL

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
July 1, 1969 to April 8, 1970 - Final Report

5. AUTHOR(S) *(First name, middle initial, last name)*

C. F. Anderson, A. Anderson, and O. P. Credle, ARO, Inc.

6. REPORT DATE October 1970	7a. TOTAL NO. OF PAGES 66	7b. NO. OF REFS 8

8a. CONTRACT OR GRANT NO. F40600-71-C-0002 b. Program Element 64719F c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) AEDC-TR-70-220 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* ARO-PWT-TR-70-220

10. DISTRIBUTION STATEMENT This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Arnold Engineering Development Center (XON), Arnold Air Force Station, Tennessee 37389.

11. SUPPLEMENTARY NOTES Available in DDC.	12. SPONSORING MILITARY ACTIVITY Arnold Engineering Development Center, Air Force Systems Command, Arnold Air Force Station, Tenn. 37389

13. ABSTRACT Tests were conducted in the Aerodynamic Wind Tunnel (1T) of the Propulsion Wind Tunnel Facility to determine the effects of test section plenum chamber volume on the centerline Mach number distributions, wave-cancellation properties of perforated walls, model force data, and tunnel acoustics at Mach numbers from 0.6 to 1.3. Results were obtained with plenum chambers of four different sizes at plenum-to-test section volume ratios between 8.3 and 0.8. Reducing plenum volume produced no measurable effect at Mach numbers below 0.95. At Mach numbers above 0.95, decreasing the plenum volume increased the internal plenum losses, increased the plenum suction requirements, and increased the centerline Mach number deviations; however, the Mach number deviations were small at Mach numbers below 1.15. Reducing the plenum volume also produced a small increase in the effective wall porosity but had no measurable effect on measured model forces except to increase the forebody drag coefficient at Mach numbers above 1.05. Changes in the plenum volume had no significant effect on tunnel acoustics.

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Arnold Engineering Development Center (XON), Arnold Air Force Station, Tennessee 37389.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
wind tunnel testing						
testing facilities						
development						
flow distribution						
acoustics						
transonic flow						
AGARD Calibration Model						
cone-cylinder						
ogive-cylinder						

AFSC
Arnold AFS Tenn